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Tertiary lignite of Brandon, Vermont, and its fossils. G. H. Perkins	499–516	86–87	1	.25	.35
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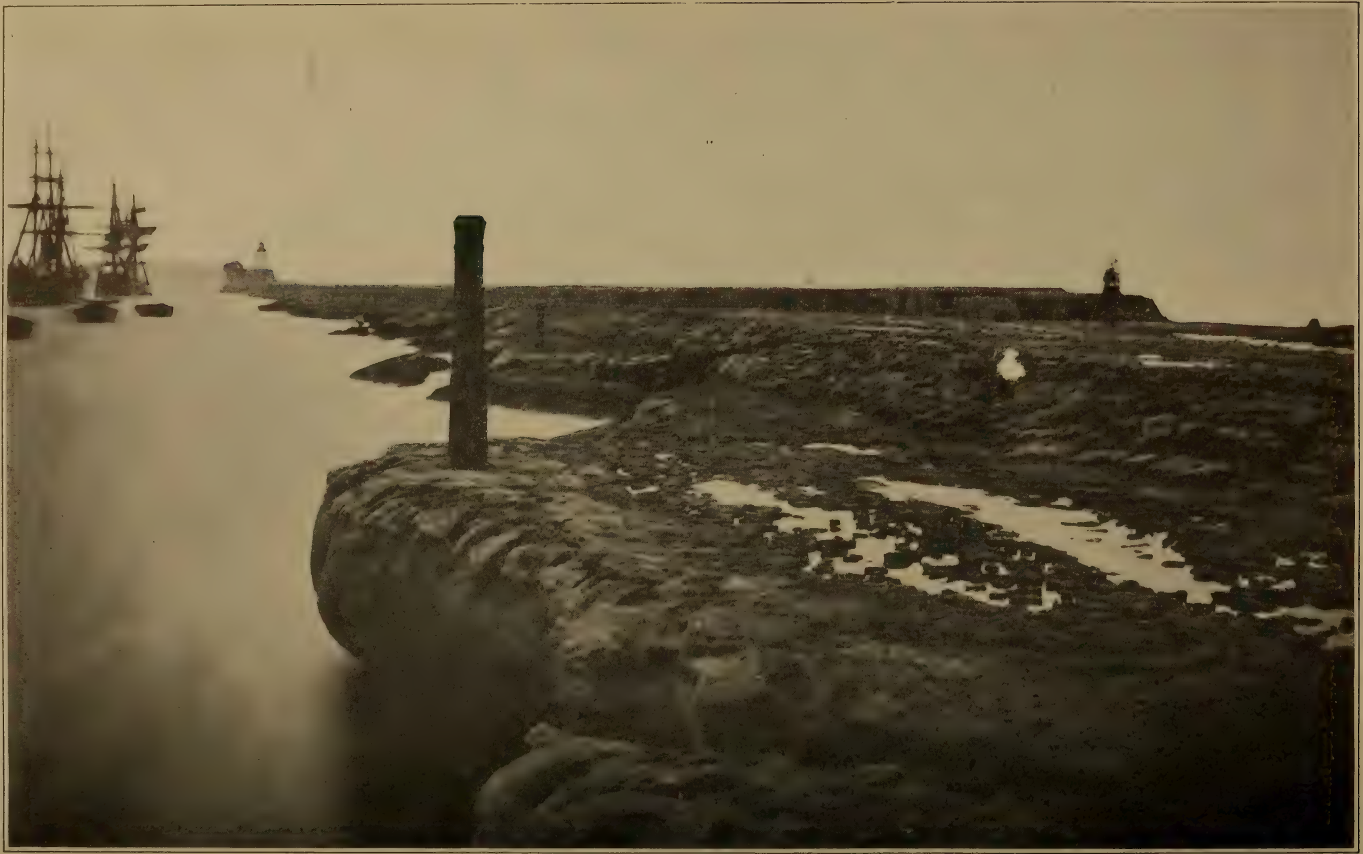
CORRECTIONS AND INSERTIONS

All contributors to volume 16 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 11, footnote; *for* “1851” *read* 1587 and omit “317 years ago.”
“ 129, plate 30, figure 2, *for* “dentrified” *read* devitrified.
“ 131, in the title; *for* “in” *read* of.
“ 133, foot-note, *for* “Ellis” *read* Ells.
“ 144, line 19 from top; *for* “united by a hyphen” *read* on top of page 142.
“ 146, line 16 from top; *for* “of” *read* or.
“ 149, line 14 from top; *before* the “:” *insert* an interrogation point.
“ 157, title of figure 1, *for* “Sketch map of” *read* Section across.
“ 211, page heading; *for* more *read* less.
“ 287, line 16 from top; *for* “important” *read* impotent.
“ 298, line 9 from bottom; *for* “cambro-ordivician” *read* cambro-ordovician.
“ 299, page heading; *for* “cambro-ordivician” *read* cambro-ordovician.
“ 302, line 15 from bottom; *for* “gniess” *read* gneiss.
“ 312, plate 57, figure 1; *for* “vein” *read* rim.
“ 313, plate 58, figure 1; *for* “vein” *read* rim.
“ 322, line 13 from top; *for* “micro-ophitic” *read* microphitic.
“ 328, line 4 from bottom; *for* “pre Cambrian” *read* pre-Cambrian.



THE STONE REEF AT PERNAMBUCO

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 16, PP. 1-12, PLS. 1-11 JANUARY 31, 1905

STONE REEFS ON THE NORTHEAST COAST OF BRAZIL*

ANNUAL ADDRESS BY THE PRESIDENT, JOHN CASPER BRANNER

(*Read before the Society December 29, 1904*)

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INTRODUCTION

It is proposed to give very briefly in this paper the results of studies of the stone reefs on the northeast coast of Brazil, which were made in connection with a general geological and geographical investigation of that region.

LOCATION, ORIGIN, AND STRUCTURAL FEATURES OF THE REEFS

The stone reefs of Brazil are mostly in an out-of-the-way part of the world. They lie along the northeast coast of that country, between south latitudes 3 degrees 43 minutes and 16 degrees 30 minutes. Only one of these reefs is where it is readily accessible to trans-Atlantic steamers, and that is at the port of Pernambuco. The others are scattered along a coast which has no commodious harbors, and are therefore but little known outside of Brazil.

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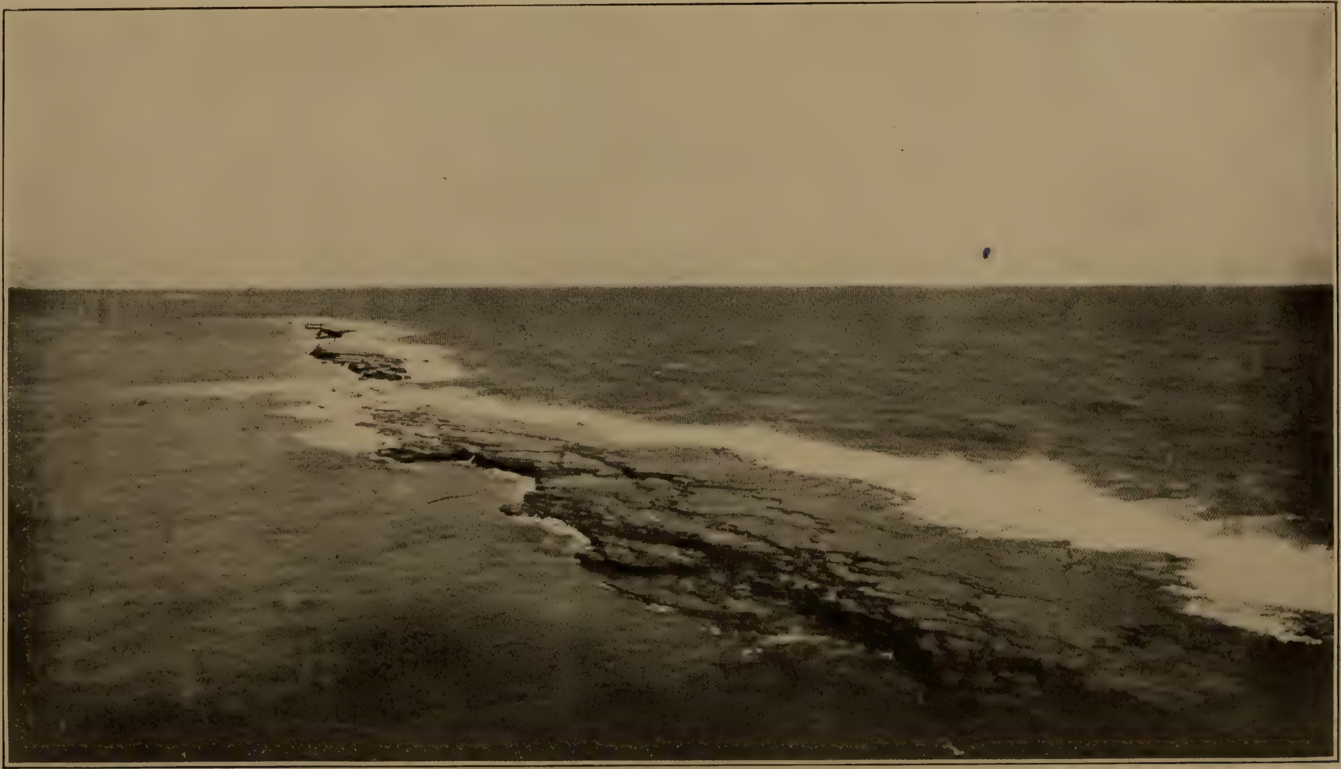
*A detailed description of these reefs is published in the Bulletin of the Museum of Comparative Zoology, VII, Geological series.

These stone reefs are unique or almost unique geologic phenomena. Darwin, who saw the one at Pernambuco, says of it that he doubts "whether in the whole world any other natural structure has so artificial appearance." Wonder at these structures is greatly increased when one finds them repeated along the coast for more than a thousand miles. Perhaps the clearest idea of them will be conveyed in fewest words if it is stated at the outset that the reefs are lithified marine spits or beaches that have been encroached on from both sides until their edges are more or less broken and angular and their surfaces swept clean of the loose, unconsolidated portions. This theory of their origin appears to be supported by the great bulk of the data collected. Only a few of the more important features of the reefs, however, can be mentioned in this place.

Where exposed at the surface the reef rock is sandstone, often almost as hard as a quartzite and ringing under the hammer like a clink-stone, but sometimes, and locally, it is only moderately hard. It contains abundant shells and other remains of animals and calcareous plants, apparently of the same species as those now living in the ocean alongside. The beach sands in the vicinity of the stone reefs invariably contain similar remains and abundant small fragments of shells, corals, and of other lime-secreting organisms. Except in the matter of hardness and compactness, the rock of the reef is therefore scarcely distinguishable from the present beaches. The cementing material of the hard rock is lime carbonate, which sometimes contains a little iron also. The rock has a remarkably fresh appearance and the shells imbedded in it usually retain their bright colors.

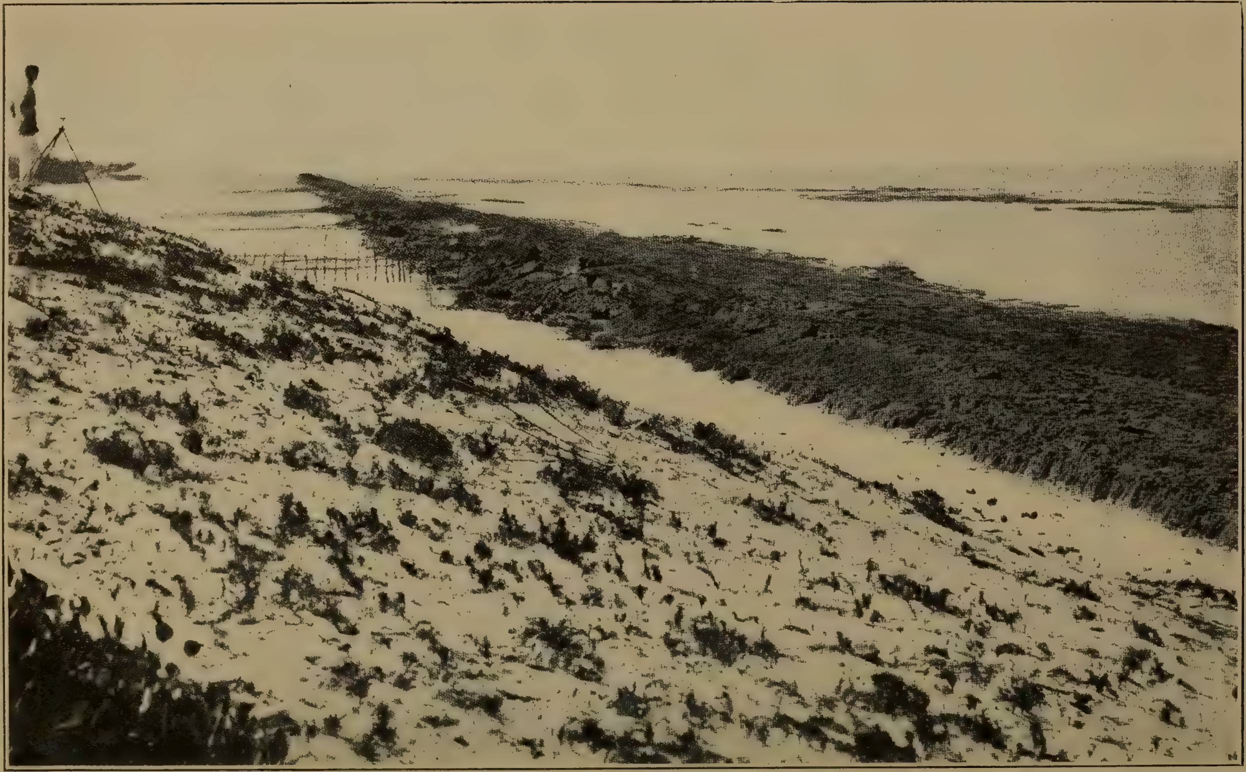
A section across a reef invariably shows the beds dipping toward the ocean at an angle varying from 2 to 20 degrees; the lower angles are the more common. In the gross structure no difference is apparent between the beds on the ocean side and those on the landward side.

In 1874 three drill holes were put down by the Brazilian government on the stone reef in front of the city of Pernambuco under the direction of the English engineer, Sir John Hawkshaw. The records of these holes furnish the only data we have of the thickness of the hard sand rock and of the nature of the underlying strata. The deepest hole had a depth of 17 meters.



SANDSTONE REEF AT RIO GRANDE DO NORTE

As seen from a fort on the reef. The seaward dip of the beds is well shown by this reef



SOUTH END OF CAPE SANTO AGOSTINHO STONE REEF WHERE IT JOINS THE LAND

There is a long pool on top of the reef

Record of a Boring on the Pernambuco Stone Reef

	Meters
Hard reef rock	2.95
White sand	1.22
Shells	1.10
Gray sand	0.65
Broken rock	1.22
Dark sand	2.10
Mottled clay	1.80
Yellow clay	0.70
Gray sand	3.50
White sand	2.20

In another bore the hard reef rock at the top was found to be about 4 meters thick; otherwise the records of the two other holes closely resemble this one. It is not known what is meant in the record by "broken rock." In none of the holes was there any repetition, at greater depth, of the hard top rock; the underlying materials were either clays or they were loose and fragmental.

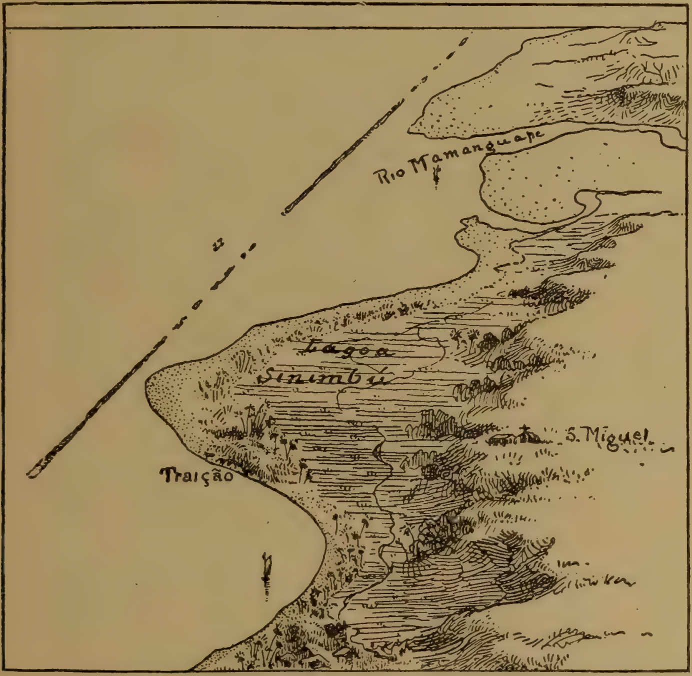


FIGURE 1.—*Bird's-eye View of the Region about Traição and the Mouth of Rio Mamanguape.*

Showing the relations of the stone reef to the shore.

The reefs are off the shore a little way and approximately parallel with it. Usually they have one end connected with the land, at least during low tide, while the free end stands across the mouth of stream, embayment, or estuary; sometimes, however, they are not connected with the shore at all, at any stage of the tide. At high tide they are about flush with the surface of the water, while at low tide they are exposed like long, low, flat-topped walls or breakwaters. In width they vary from a few paces to 450 feet; in length they are from a few hundred feet to 8½ miles, the total length being concealed by sand, which covers one end. Commonly they are almost straight; when they curve at all the curves are gentle and only perceptible when one looks along them lengthwise or when they are carefully mapped.

These remarkable natural walls of sandstone accompany the shores of northeastern Brazil, with many interruptions, from Ceará to Porto Seguro, a distance of 1,250 miles. With unimportant exceptions, they do not occur beyond these limits.

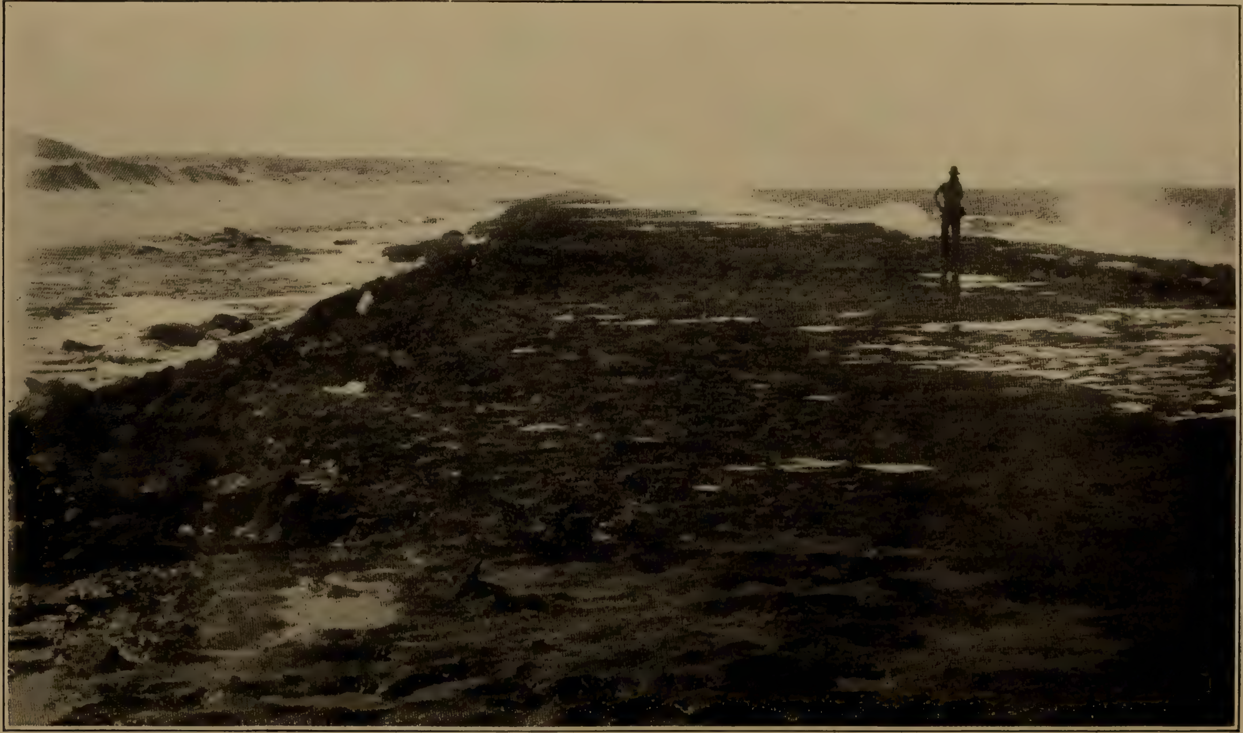
Factors in the Formation of the Reefs

IN GENERAL

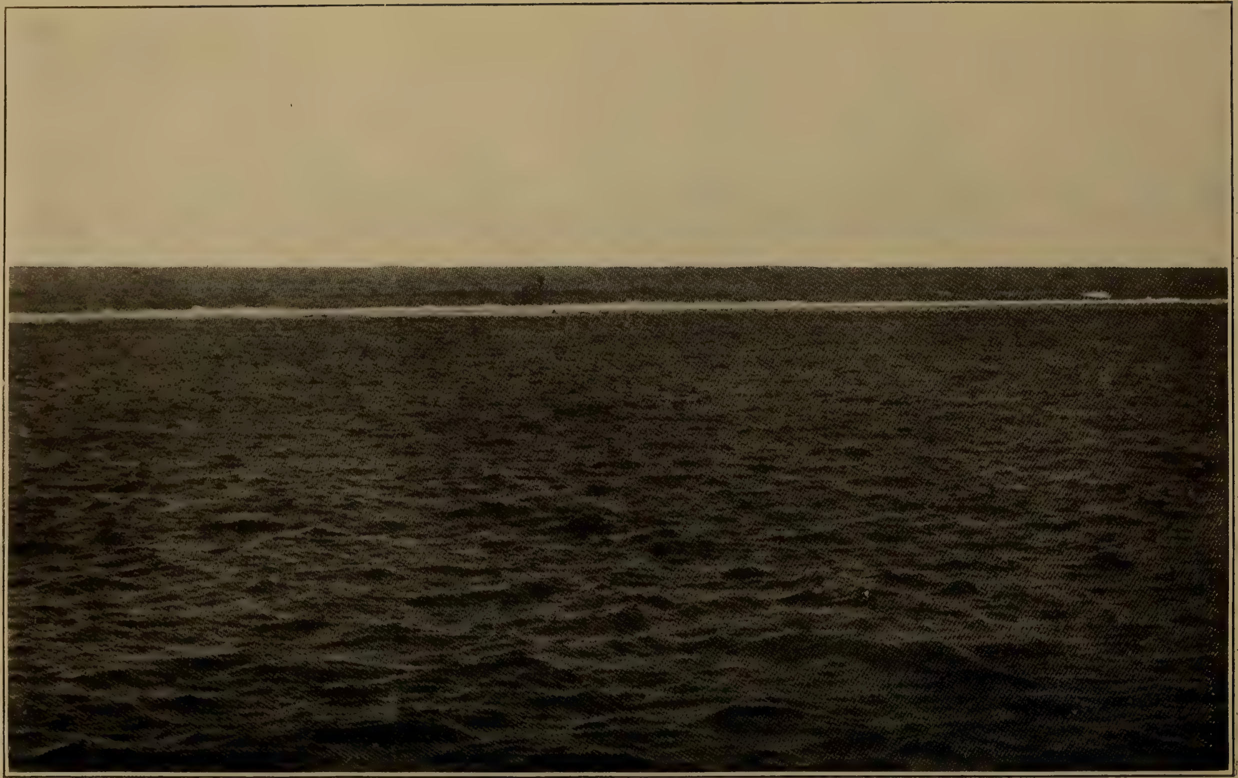
Having stated the broad theory of the origin of these stone reefs, I shall not weary the reader with the tedious process of elimination by which the accepted conclusions were reached, but shall invite attention directly to their history as finally worked out in a study of the problem which has been carried on with various interruptions for nearly thirty years.

HISTORY OF THE COAST

It will be necessary first to briefly outline the geologic and geographic history of this particular coast. The greater part of the rocks of the coast region are marine sedimentary beds, apparently of Eocene age. During Miocene times the coast seems to have stood several hundred feet higher than it does at present, and narrow valleys were cut in the Eocene beds, mostly at right angles to the coastline. This period of erosion was followed by a depression, when many new bays were formed by the valleys which lie near the coast. There have been some changes of level since this period, but they have not been great, the evidence nowhere suggesting a movement exceeding 30 or 40 feet. In the meantime the strong on-shore waves and the in-shore currents rapidly cut away the soft Eocene sediments of the headlands and threw them into the reentrant angles of the coast. This process continued until the mouths of the bays were completely or nearly closed and the entire coast made as nearly straight as it is possible for as long a coast to be. Streams flowing into these narrow bays silted them up from the upper ends. Marine erosion was so vigorous, however, that several such bays were almost completely closed long before the land sediments filled them up.



THE CUNHAHU STONE REEF AT LOW TIDE



PORTO SEGURO REEF

View taken from a steamer behind the reef at high tide. The surf line is in outer face of the reef

In this way were formed the coastal lakes of the state of Alagôas, which are brackish water lakes lying between watersheds from 200 to 500 feet high and separated from the ocean by low sand spits.

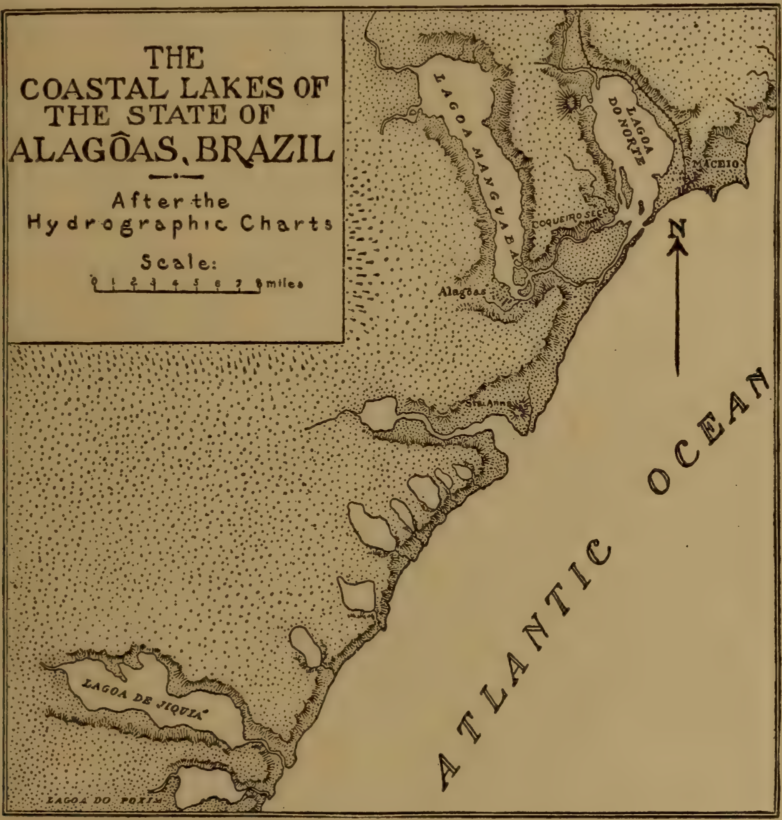

THE COASTAL LAKES OF THE STATE OF ALAGÔAS, BRAZIL
After the Hydrographic Charts
Scale:
0 1 2 3 4 5 6 7 8 miles
LAGOA MANGUABA
LAGOA DO NORTE
MACEIO
COQUEIRO SECCO
Alagôas
N
Sta. Anna
ATLANTIC OCEAN
LAGOA DE JIQUIA
LAGOA DO POXIM

Figure 2.—*Coastal Lakes of the State of Alagôas, Brazil.*

CLIMATE OF THE INTERIOR

It is necessary at this point to direct attention to certain climatic and drainage peculiarities of this northeastern corner of Brazil which affect the problem of the stone reefs.

If the reefs of northeast Brazil are but little known outside of that country, the climate of the interior along this coast is even less known. Everyone has heard of the great amount of rainfall about the mouth of the Amazon, and every writer on Brazil has something to say of the abundant rains of Rio de Janeiro. At one station of the edge of the plateau, south of Rio, the annual rainfall amounts to 11.7 feet. As the region of the stone reefs lies between Rio and the mouth of the Amazon and is entirely within the tropics, it appears to the casual observer that it must also be a region of great rainfall. As a matter of fact the country about cape Saint Roque and for hundreds of miles west, southwest, and northwest of there is a region of devastating drouths.

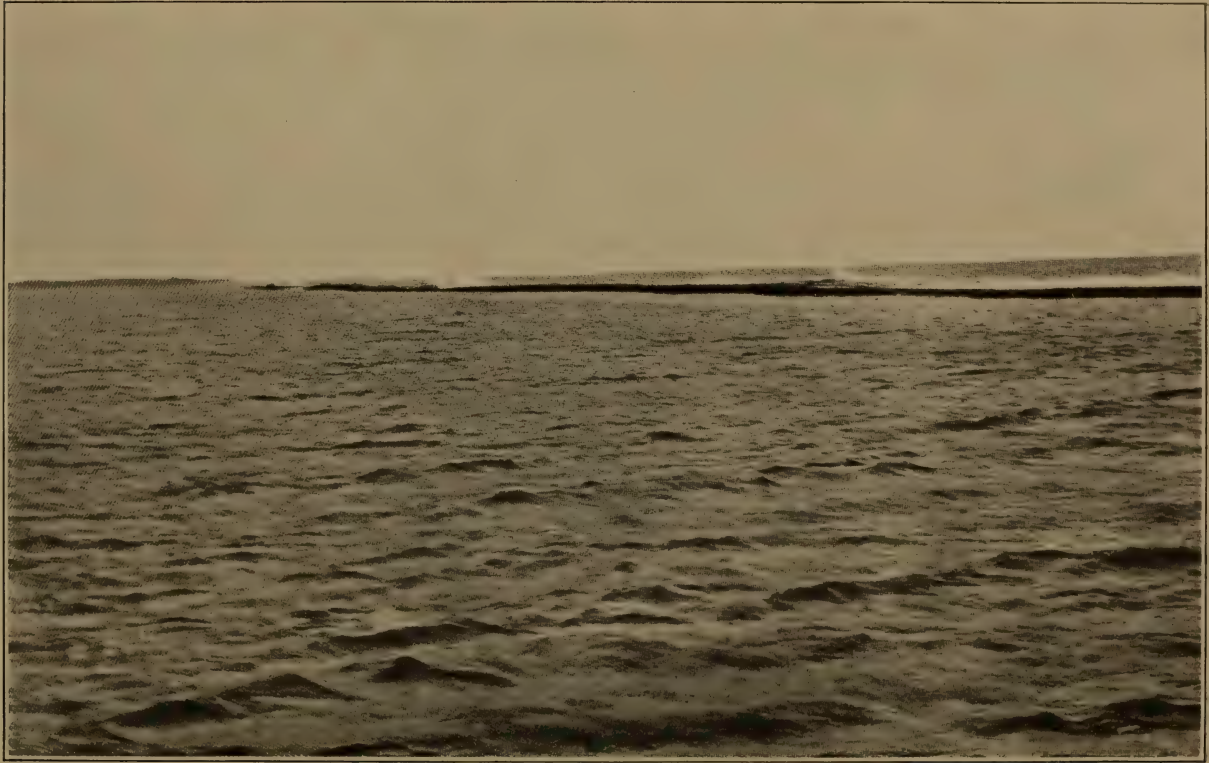
PERIODICITY OF THE STREAMS

Ordinarily the rains fall during two or three months of the year, but some years the annual rains do not come, and the dry season is drawn out to an entire year, to two years, or even to five or six years. At such times all vegetation away from streams is parched, the streams disappear, cattle die of thirst, and sometimes the people themselves are compelled to leave the region. When the rains do fall they are frequently torrential, and the precipitation even in this region of drouth is in fact much larger than at Pará, and many other notoriously wet places. The result of these conditions is that the streams of the region are strongly intermittent, some of them being big enough to float an ocean steamer at one time, and completely disappearing during the ordinary dry seasons, to say nothing of years of severe drouths.

The Rio São Francisco is the only large perennial river along this entire strip of coast, and that river rises, not in the drouth region of northeastern Brazil, but about latitude 21 degrees south, far to the west and south of the highlands of Minas Geraes and more than 1,000 miles from its mouth. On the maps many other rivers are shown, to be sure, but they are all more or less intermittent. Under such circumstances it follows that the intermittent streams flow boldly into the ocean only during the season of rains, while during the dry season they become so enfeebled that the waves of the ocean throw their own silts and the beach sands back into their mouths, and in some cases complete barriers are thus built between the land water and the sea water. These processes have been in operation along the northeast coast of Brazil ever since the land took on its present approximate form.

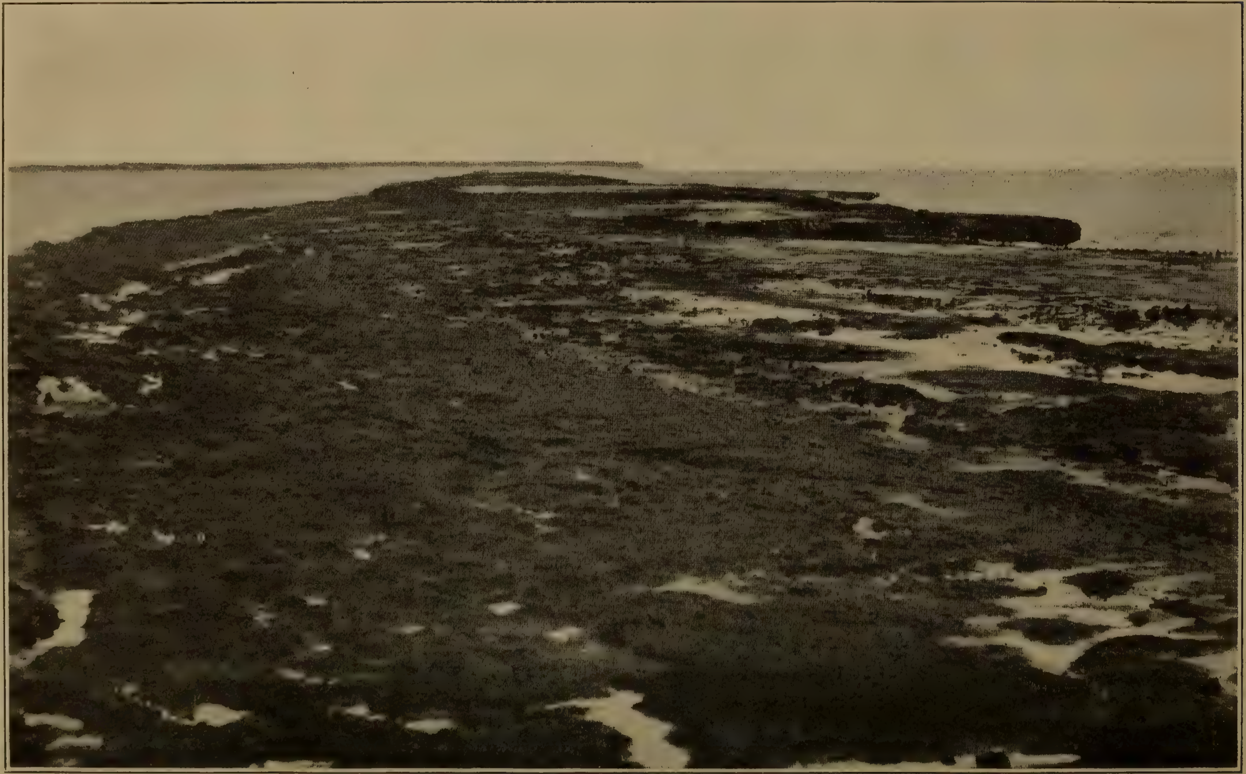
CLOSED STREAMS

My studies of the stone and coral reefs have been carried on partly in small boats and jangadas or rafts, but I have also walked several hundred miles along the beach for the purpose of examining them and of seeing their geographic and geologic surroundings. Naturally one traveling along the beach would expect to find difficulty in crossing the streams, but as a matter of fact during the longest trip made on foot and at the end of the rainy season only two streams were found that could not be waded in a distance of something over 200 miles. At the mouths of several rivers there was connection between the ocean and the streams only during high tide, and at several other places where streams were to



THE MAMANGUAPE STONE REEF

Taken at low tide from the port on the landward side



LOW TIDE ON THE MAMANGUAPE STONE REEF

be expected, there were what are known in that country as "rios tapados" or shut up streams—that is, streams whose mouths are completely closed by bars across them. At one place a stream was waded that was cutting through a sand bar and running from the ocean landward; at two places gaps were found that had been cut in this way, but as they were passed at low tide, there was no water flowing through the breaks. The disposition of the sand, however, left no doubt about the water having flowed from the ocean toward the stream.

VEGETATION

Another important fact is that the region under consideration is in the tropics, and wherever there is fresh water, vegetation is rank. The banks of streams are everywhere overgrown with a dense jungle, bodies of fresh water are covered and filled with aquatic plants, while the densest of mangrove swamps cover the tide flats of the region of salt and brackish water.

DENSITY OF THE SEA WATER

The other element of the problem is the density of the ocean water along the part of the Brazilian coast on which the stone reefs occur. In volume I of the Challenger reports, "Physics and chemistry," data have been brought together and a chart constructed showing the oceanic areas of different densities of the surface waters. This chart shows that the areas of the highest densities are in the Red sea and the Mediterranean sea; these, however, are land-locked basins. The highest densities in the open ocean form two areas in the Atlantic: one being near the middle of the ocean, lying between northern Africa and the West Indies; the other being in the south Atlantic and hugging the coast of Brazil from cape Saint Roque to south of Rio de Janeiro.

It is worthy of note that the area of high Atlantic density as represented in the Challenger chart does not quite fit the area of the stone reefs. The map seems to show the dense area to be too far to the south to suit the theory of the reefs here put forward. This is probably due in part to a lack of density data, especially for the dry season, along the coast of Brazil northwest of cape Saint Roque, and extending half way from there to Pará. The southern limit of the high density lies south of Rio de Janeiro and far beyond the southern limit of the stone reefs. The absence of reefs in this direction is readily explained by the fact that rainfall on this part of the coast is very much larger than it is farther north, and the streams are therefore able to keep their mouths open. In connection with the subject of climatic conditions it should be noted that the long dry season which enfeebles the streams and permits the waves to dam them back must likewise be the season of the highest density of the sea water. The South Atlantic equatorial currents flow westward from near the coast of Africa and split on cape Saint Roque. In the season of drouths the surface density must be considerably increased, especially near the land and the shallow continental shelf.

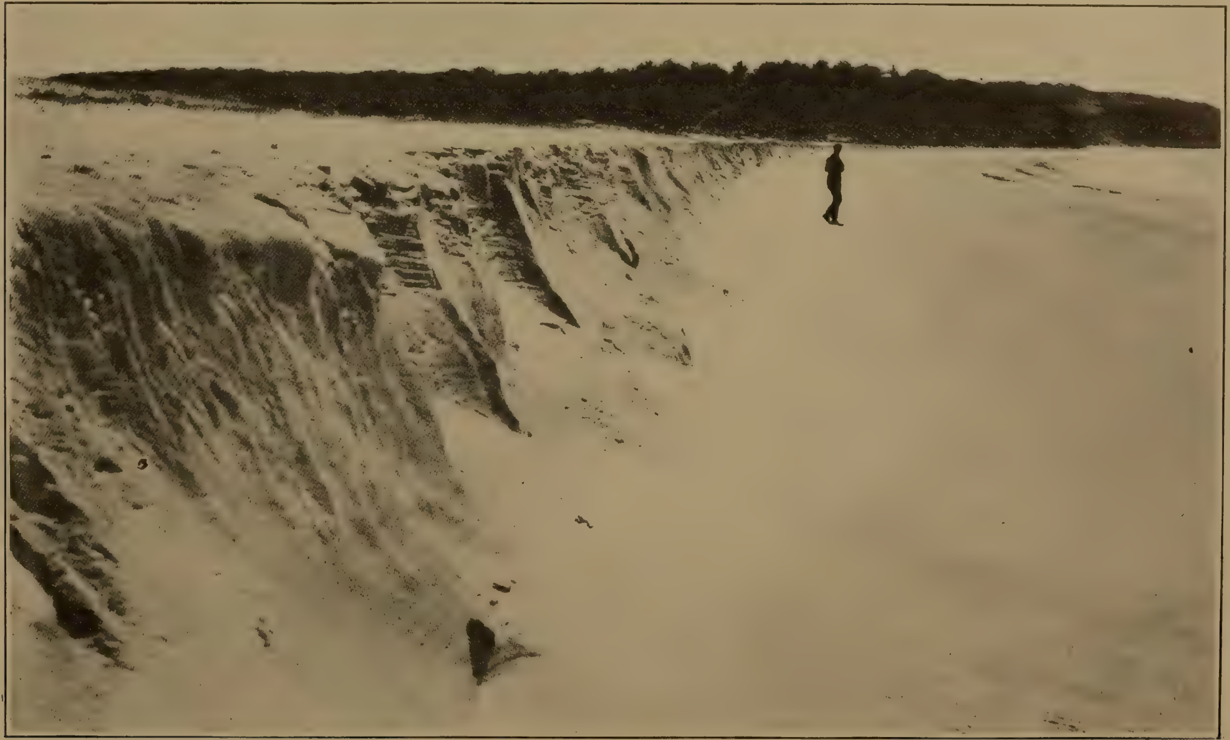
Attention is called to the absence of reefs between Bahia and the mouth of Rio São Francisco. This is attributed to the influence of the large body of fresh water discharged by the São Francisco. The reefs begin a short way north of the mouth of that stream, but the currents set southward and shoreward along this part of the coast. This permits the formation of reefs north and prevents it south of the stream.

CALCAREOUS SANDS

One more factor is this: The ocean alongside is warm and teems with marine tropical life. There are many coral reefs along the coast, and everywhere are shell-bearing mollusca, ichinoderms, crinoids, crustacea, worms, corals, calcareous algæ, and other lime-secreting organisms. All of these organisms contribute abundantly to the beach sands.

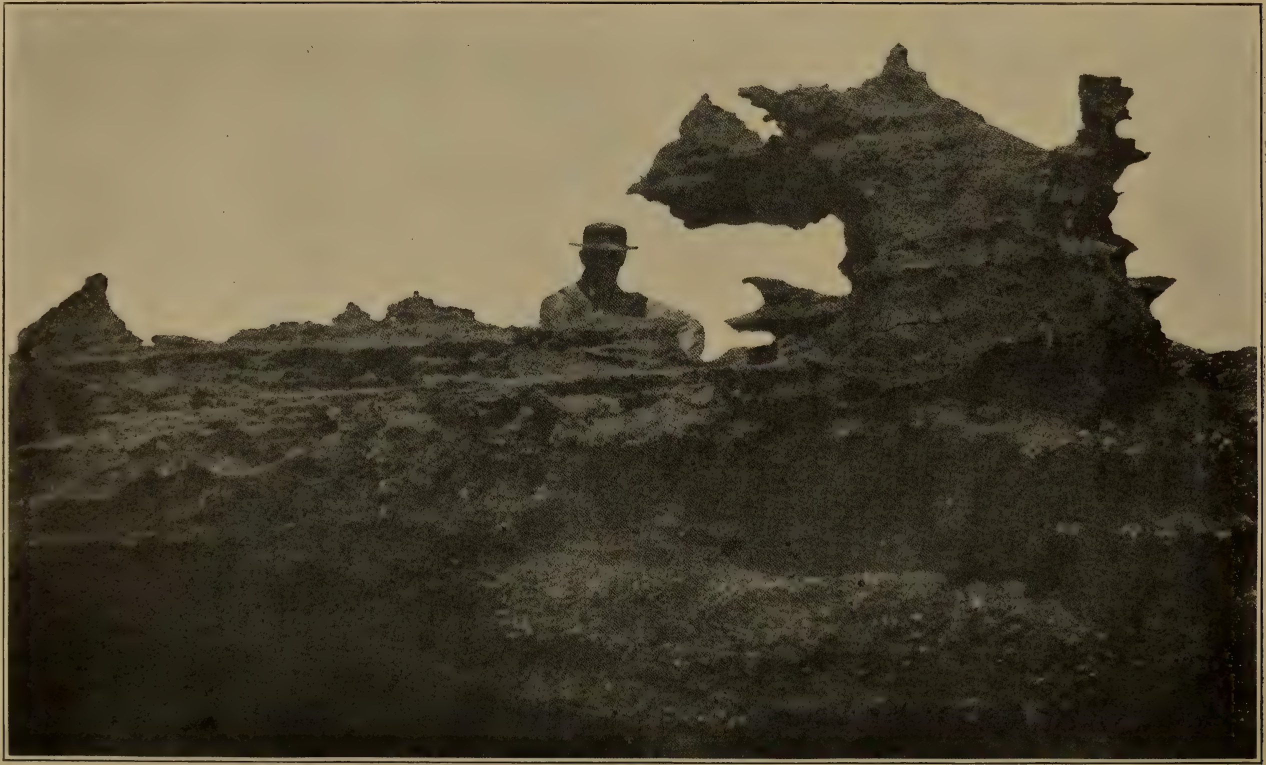
The Course of Events

With this data in hand, we may now observe the course of events on the coast under consideration. We have an old coastline with long, nearly straight, sandy beaches. The sands are rather coarse and are commonly mixed with fragments of calcareous skeletons of the animals and plants living in the ocean. Across old embayments the sands have been thrown back landward by the waves until in many places the weak drainage is partly or entirely shut off from the ocean by banks of sand. In and about the pools, lakes, or sluggish streams thus formed, abundant aquatic and semi-aquatic plants live and die. The fresh water is thus rendered acid by the presence of large quantities of carbon dioxide produced by organic decomposition. The acid water on the land side percolating through the embankment of sand at low tide attacks the calcareous matter in the sand and passes seaward with it in solution, but as it comes in contact with the dense sea-water on its way through the sand, the lime carbonate in solution is deposited in the interstices between the sand grains. In time the interstices are completely filled, and the sand bank is hardened and so solidified that the water can no longer soak through it. The process must then of a necessity come to a halt at that particular place, and percolating waters must either seek other loose sands or they must be turned aside by the now hardened and impervious spit and compelled to flow through the open channels. The percolation of fresh and salt waters would be very much the same whether the fresh waters to landward were completely damned in or were separated from the sea by a long spit, around which it had to flow at ebb tide. Thus the streams by the help of the sea build of



SAND SPIT AT TRAIÇÃO ENCROACHED ON BY THE SEA

There is a lake to the left of the spit



ETCHED SURFACE OF A STONE REEF

the loose sands a rock barrier against the onslaught of the sea itself. It is now clear why the hard rock occurs only at the top of the reef and why it is not thicker. It is because the seaward percolation of the fresh water is not likely to occur at a depth exceeding or much exceeding the depth of the stream behind the sand spit, and it seems probable for this reason that the hard top stratum varies somewhat in thickness and in width, the stronger streams having the thicker and broader reefs in front of them and the weaker ones having the thinner and narrower reefs.

Coast Changes

A coastline is never quite at a standstill. The shore currents average a little different one year from those of another. Coral reefs and the average of the winds during a given season help on some of these changes. The result is that there is always a tendency to cut a little more at one point and to fill a little more at another. In the case of such a spit as has been described these changes may in time either bury it under new accumulations of sand or its unconsolidated edges may be undermined on either side or on both sides until its edges break down. If the hardening process has not proceeded far enough at the time of encroachment the entire structure may be broken up. It is evident that many reefs have thus been attacked by the sea and partly destroyed before the consolidation was completed. Broken lines of fragments mark the position of many such reefs along the Brazilian coast. Even the strongest of the reefs are undermined here and there, so that the tides ebb and flow beneath them, or natural arches so formed have been broken down, and their angular fragments fill the gaps. Some reefs are buried or partly buried beneath loose sands. At Rio Formoso the reef passes through a sandy cape and sticks out on both sides of it. Several reefs are buried at one end and exposed at the other, while still others are exposed their entire length.

Protective Agents

But while some reefs are broken up by the surf many others have resisted for hundreds of years, perhaps for thousands, without showing, during historic times at least, any marked signs of change. When a reef is partly undermined, especially on the seaward side, the fragments that break off fall with their outer margins considerably lower than the inner margins. These pieces, on sinking to the bottom, so lie as to afford protection to the rest of the reef. Waves striking these flat blocks glide up their sloping surfaces and lose their force before hitting the main reef.

Another important factor in the preservation of the reefs is organic life. The seaward faces of the reefs are everywhere covered with serpulæ, sponges, seaweeds, mollusks, and the many other forms of life so abundant in tropical seas. These plants and animals form a protective coating that successfully resists the most violent waves. It is true that sea urchins occasionally bore into the reef rock, but the wearing done in this way is insignificant when compared with the protection afforded by other animals and plants.

Uniform Width of the Reefs

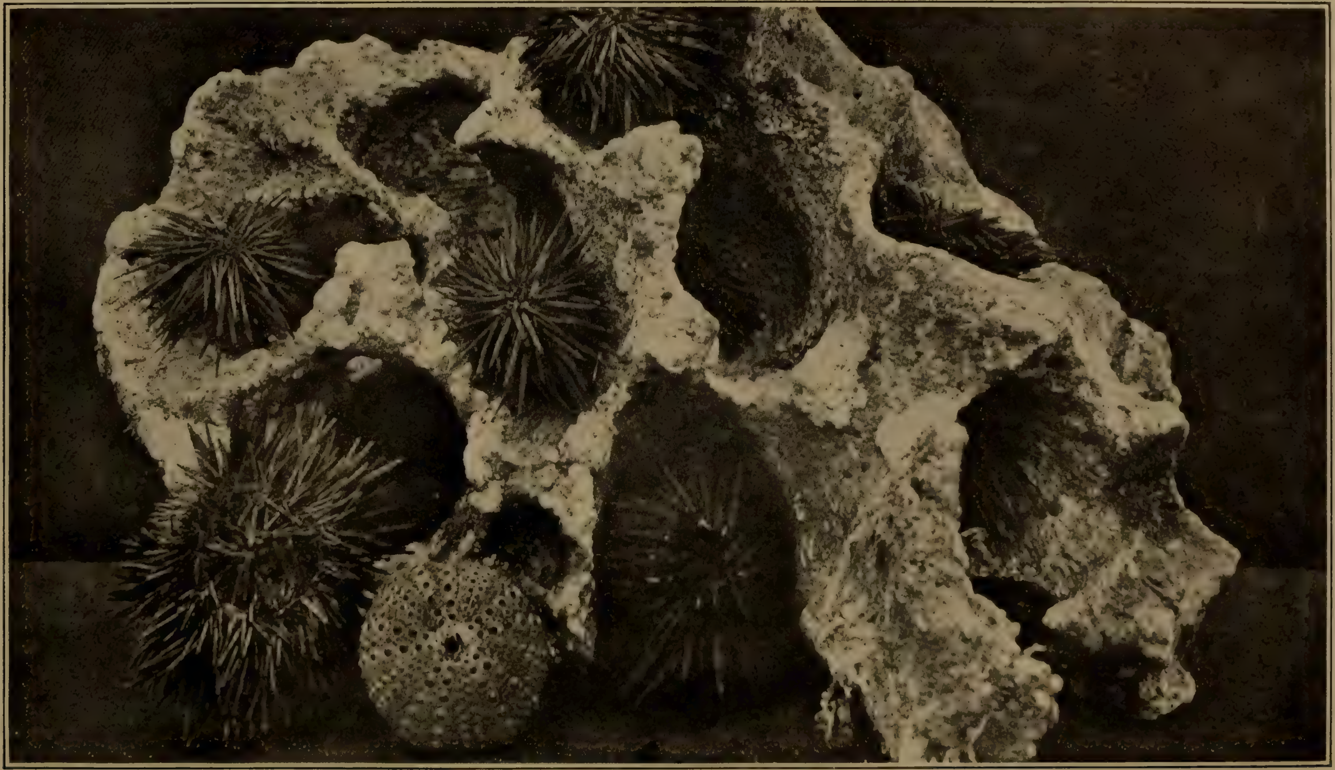
The nearly uniform width of a reef appears to be due to the ebb and the flow of the tides and the approximate uniformity of the distance the seepage water can move through the sands between tides. The ebb and the flow of the tides are repeated in the sand barriers in so far as the sand will permit ebb and flow. Some reefs are wider than others; this is probably due, in part at least, to the fact that a larger estuary has to discharge more water in a given time than a small one. There is therefore more head and more hydrostatic pressure within the sands, so that the water flows farther in a given time when the estuary is larger. As waters flowing from the larger estuaries must move faster, channels having the same width must have a greater depth, and it follows from what has gone before that the hard strata of the reefs in front of the larger bodies will also be thicker.

Cause of the Straightness of the Reefs

The straightness of the reef has never been satisfactorily explained, for there are few beaches or spits on this part of the Brazilian coast as long and straight as the reefs. This straightness is thought to be due to their having been solidified in the early part of their history as spits in front of estuaries, at the time when the spits were narrow and approximately uniform in width. It is believed, however, that some of the reefs are more nearly straight than were the beaches and spits from which they were found. This will appear if we imagine a long beach with a few gentle curves in it and behind it a stream or estuary approximately parallel to the beach, but somewhat more crooked. The waters from both sides of such a spit will meet along a line equidistant from the two water margins, and this line will be more nearly straight than the crooked stream behind or the curved beach in front. If the beach in such a case were straight the reef would be slightly crooked.

Stone Reef Making still in Progress

The process of stone reef formation is believed to be still in operation. The new reefs, or perhaps it would be better to say the conditions favorable to forming new reefs, are now to the landward of the old ones. At



SANDSTONE REEF ROCK BURROWED BY SEA URCHINS

Traição, for example, the conditions favor the formation of a new reef behind or landward of the old one where the waters from Lagôa de Sinimbú percolate through the sand neck that separates the lake from Traição bay.

At other places the new reef may be outside or seaward of the old one, but in these places the old reef is invisible, being buried beneath the later accumulations of sand. In the city of Pernambuco one hears of rock like that of the stone reef having been struck in digging wells, nearly or quite a mile landward of the present reef. If these are buried reefs they are considerably older than the one now in front of the city.

Similar Reefs outside of Brazil

It was stated at the outset that these stone reefs were unique or nearly so. Nowhere have I either seen or been able to learn of such phenomena save at a few places on the coast of Asia Minor in the Mediterranean sea. From the descriptions, the reefs at Jaffa appear to be one of the best of those of the Mediterranean. The climatic conditions and the density of the sea water lead one to expect similar reefs along the shores of the Red sea, but thus far it has not been possible to ascertain whether such reefs exist there.

In southern California the climatic conditions are favorable on the side of the land. Sands have been thrown back across the mouths of the streams until many of them are completely closed nearly the year round by a beautiful series of sand embankments. The water of the ocean alongside, however, is not so dense as that of the northeast coast of Brazil, nor is there a tropical climate with its rank vegetation; but as far as can be seen these are the only elements lacking for the formation on that coast of lithified spits or reefs of sandstone. On the coast of Brazil the reefs are formed under a remarkable combination of geographic forms and climatic conditions on the land and on the sea—a beautiful illustration of the nice balancing of the forces of nature.

Literature of the Stone Reefs

A great many people have had something to say about the reef at Pernambuco, but most of the references to it are simply of the nature of exclamations at its appearance and commercial importance. Most writers state that it is a coral reef, probably getting their information on this subject from the officers of the vessels on which they chance to be traveling, and the officers in turn taking it from Findlay's "Sailing directory for the South Atlantic ocean." It is certainly remarkable that the book mentioned—a standard work for sailing masters—down to the edition issued in 1898 states that the Pernambuco reef is coral.*

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* Gabriel Soares de Souza first pointed out in 1831 that 317 years ago this reef was sandstone This was satisfactorily confirmed by Von Olfers in 1832, by Charles Darwin in 1841, and by later writers.

The writings of early travelers on this subject have at least this value, they show that there have been no marked changes in the elevation or appearance of the reefs during the last 250 years or more. Only four or five persons have written short articles of value upon the geology of the Pernambuco reef; these are Darwin, Hartt, Rathbun, and Hawkshaw, and perhaps Liais. With the exception of the two reefs south of Bahia, described by Hartt, little was known of the other stone reefs prior to the personal examinations made by the present writer.

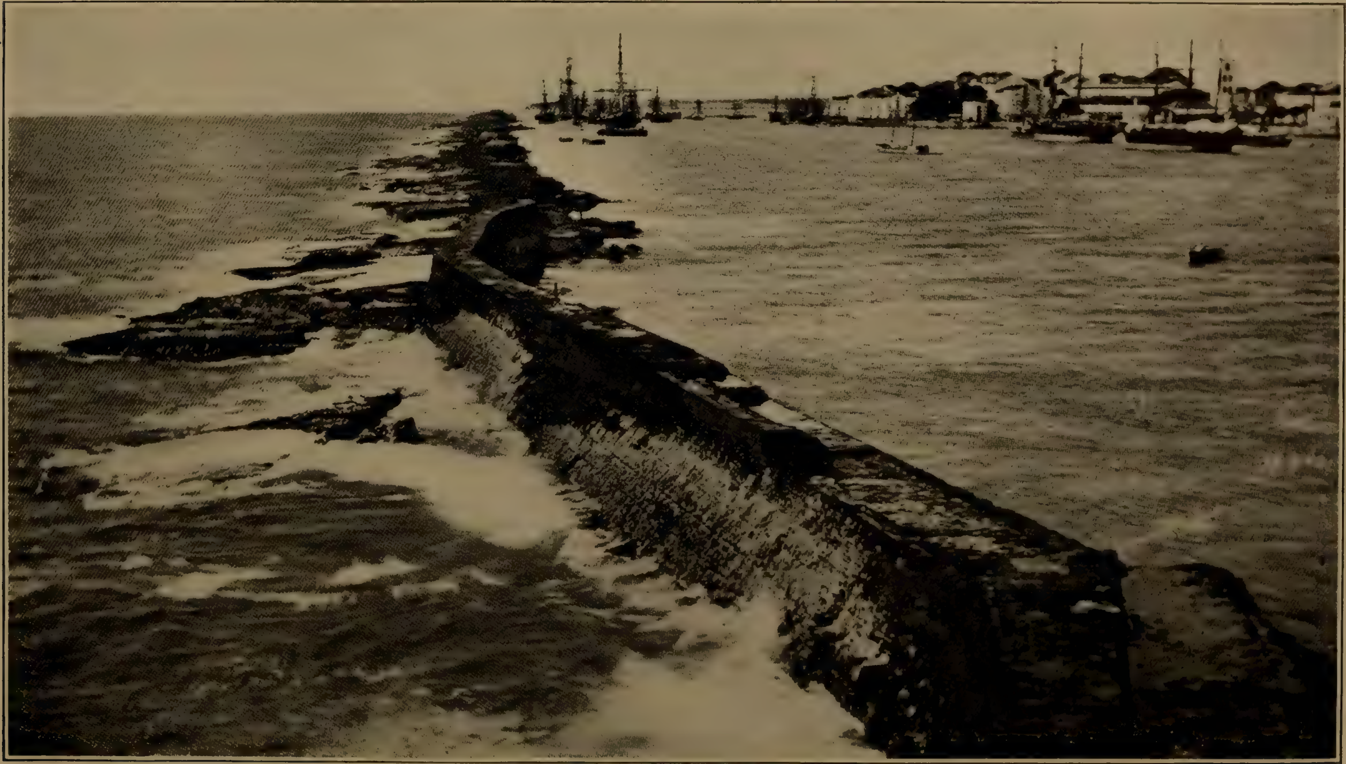
The theories of the origin of the reefs put forward by these authors are all more or less correct so far as they go, but none of them take into consideration the fundamentally important factors in the case, namely, (1) the age and submarine topography of the coastline; (2) the concentration of the rainfall and periodicity of the streams; (3) the influence of a tropical climate; (4) the aridity of the interior; (5) the density of the sea water; and none of them account satisfactorily for the straightness, uniform width, or the shallowness of the lithified portions of the reefs or for their peculiar and restricted geographic distribution.

Commercial Importance of the Reefs

Inasmuch as the northeast coast of Brazil is without large bays, excepting that of Bahia, these stone reefs have played an important part in the commerce of northern Brazil. They form small harbors, behind which the little cities have grown up, or where the coasting vessels load and unload, or take refuge during stormy weather. The largest city built behind a reef is Pernambuco, and that is a city of 190,000 inhabitants. The rock of the reef was formerly extensively quarried for building purposes. Nearly all of the old dwelling houses, stores, churches, monasteries, fortifications, and occasionally the sidewalks of the cities along the coast are made of stones taken from the reefs. Of late years, however, the Brazilian government, realizing the danger of injury to the ports, has wisely prohibited the quarrying of the reef rocks.

Antiquity of the arid Climate

Since Cretaceous times there have been important geographical changes in the Amazon Valley region, but about the northeast corner of Brazil there have been no such changes. It is highly probable, therefore, that the fatal drouths common in Ceará and the adjoining states of Brazil have been characteristic of that region since Cretaceous times, and they must continue to occur as long as the present geographic conditions remain. It follows also that reefs like the existing stone reefs have characterized this coast certainly as far back in the history of the continent as Eocene times and probably somewhat earlier.



PERNAMBUCO REEF

As seen from the north end. A brick wall which has been built along the reef is in the foreground

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ICE EROSION THEORY A FALLACY

BY H. L. FAIRCHILD

(Read before the Society January 1 and December 30, 1904) *

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* The second part of this paper was presented in the abstract at the Saint Louis meeting. The theoretical discussion, part 1, was read in brief at the Philadelphia meeting.

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PART I—GENERAL THEORETICAL DISCUSSION

INTRODUCTION

Divergence of opinion.—Probably there is no subject in geology on which the divergence of opinion is so great while at the same time the observational material is so ample as that of glacial erosion. A few geologists believe that glaciers have excavated valleys and basins thousands of feet deep in solid rock, while others think that ice erosion has been inconsequential. There was a time when Joseph Le Conte and John Muir held the opinion that Yosemite valley had been excavated by Sierran glaciers, while J. D. Whitney was not convinced that glacier ice had ever even occupied the valley. Today most students of living glaciers and glacial work deny that glaciers possess great erosive power, while a group of physiographers claim that the peculiar features of Norwegian, Alaskan, and other deep valleys, including those of the New York "Finger" lakes, are due to great deepening by ice excavation. With such an abundance of concrete evidence available, it would seem as if the extreme differences of opinion and the sudden and radical shifting of views were not creditable to the science. The work of recent glaciers in varied forms is conspicuous over vast territories, and living glaciers are available for comparison in large numbers and of various classes and conditions. This diversity and changing of views suggests a psychological phenomenon more interesting perhaps than the glacial. It implies either some unusual, peculiar, and indefinite character of the glacial phenomena, or failure in accurate observation, or faulty interpretation of the facts.

Purpose of the paper.—The original plan of this writing was to present the arguments and conclusive facts against great ice erosion in central and western New York. It was, however, found desirable to preface the discussion with a review of the general theoretic problem. The paper has therefore been expanded into a general consideration of the whole problem, and will try to aid in establishing a sound conclusion on this much-disputed subject. The truth is desirable, even though it destroys the pleasure of disputation.

Use of the term "erosion."—One of the sources of disagreement in this study has been the failure to discriminate the several forms of ice erosion, to recognize its limitations, and to use a distinctive terminology. It will be necessary not merely to save circumlocution, but as aid in clear thinking, to make distinctions and to explain the use of terms.

It is conceded that glaciers have power to gather up and carry along loose material which they find in their way, and that they frequently, but not always, exercise that power. It is conceded that they can push away loosened blocks which obstruct their paths, and may thus to some extent cut down opposing cliffs or ridges; also that they can "pluck" or pull away loosened blocks, under some conditions. It is also granted that glacial ice may lift and bear away layers of stratified rocks which previous weathering has detached or loosened. It may be conceded that at the feeding grounds of alpine glaciers the valley heads may be expanded into cirques and the walls steepened, by the aid of weathering, through the pull of the ice on the frost-loosened blocks, specially where facilitated by vertical jointing. It may even be conceded that the ice may rend or tear away the weathered material so as to leave an irregular surface with shallow rock-basins, specially in crystalline rocks; and as a further concession it may be admitted that alpine glaciers can possibly do some basin-making work at the foot of steep slopes or cascades of the ice in unobstructed valleys, analogous to the basins made by the plunge of cataracts. In brief, it is granted that glaciers may produce comparatively small and shallow rock-basins in weathered crystallines, and rarely in mountain valleys, while it is generally recognized that glaciers have the power, which they use capriciously, of clearing valley, slope, or plain of weathered or loose material. They change geest and alluvium into drift. But these effects are not "erosion" in the full sense of the word as commonly used. If the advocates of "glacial erosion" limited the erosional work of ice to the operations mentioned above, there would be little occasion for any disagreement. It is evident with a very little thought that long and deep valleys and large lake basins are not produced by any of these operations, but that they would require vast and deep excavation in solid or "live" rock by the ordinary flow of the glacier in its open course. It must be admitted that the production of lake basins like those of Chelan, or Cayuga, or valleys like the Norwegian fiords imply an erosion not only vastly different in degree from the work of glaciers conceded above, but essentially different in kind or quality. The failure to make this discrimination and to recognize the limitations of ice-work is the cause of much misconception in this matter.

The term "erosion" will be used in this paper to signify the removal by the ice of firm, hard, unweathered bed-rock. For the admitted and competent work of ice other and self-explanatory terms will be used.

Character of the argument for erosion.—The argument for extreme ice erosion is founded in analogy and is almost wholly inferential. It is mainly an assumption, resting on the argumentative method of exclusion. Some topographic forms, the precise genesis of which is not clearly explained, are assumed to be the product of ice erosion because ice was the last occupant of the area. The strength of this claim on the thought of students is due to their failure to discriminate the kinds of ice-work and to recognize its limitations. Geological text-books and treatises discuss the topic only in a general and indefinite way, and with more or less qualification seem to approve the conception, or to at least admit the possibility, of deep erosion by glaciers, while the leading text-books in physical geography positively affirm deep ice erosion.

Many American geologists who are compelled by the concrete evidence to deny great erosional power to continental glaciers still have been willing to admit that alpine glaciers might produce deep cutting. This is partly a concession to the extravagant claims of the erosionists and partly due to the teaching of the text-books. Probably most geologists of the later decades began their work with an indefinite belief in the glacial origin of some lake basins, valleys, or fiords, and if they have come to new and different opinions it has been through outgrowth of the old views. The writer belongs in this class. At the Minneapolis meeting of the American Association for the Advancement of Science, in 1883, there was a spirited colloquy on this topic between J. S. Newberry and J. P. Lesley. The former held that even the basins of the Great lakes were partly, if not wholly (in the case of Erie and Ontario), the effect of glacial excavation. With a resounding blow on the table, Lesley said that "ice has no eroding power." There was a warm debate on a cold topic. To the writer Newberry was a demi-god and Lesley was a very impious mortal, but with the passing of time the conviction has come that Lesley was essentially right. Many readers of these lines can probably give similar experience.

Literature and summary of opinion.—The opinions and arguments relating to this subject are scattered through an immense volume of glacial and physiographic literature, and it seems undesirable to cumber these pages with a host of references. An excellent digest of the literature on the subject was published by Culver in 1895.* In that paper it was shown that from the time of Ramsay, 1862, who was responsible for giving currency to the idea of glacial origin of lake basins, up to 1895 very few glacialists of note were advocates for extreme glacial erosion. On the other hand, the vast majority of students of glaciers and glacial phenomena had been emphatic in denying effective erosion to glacial ice. Among these were Bonney, Judd, Neumayer, Heim, Forel, Whymper, and most American geologists who had spent much time on living glaciers. Culver's quotation of opinions shows this striking fact, that the judgment adverse to ice erosion was almost entirely based on direct observation and field-study of glacial phenomena, while the opinions favoring great erosion were abstract and theoretic, relying chiefly on physiographic features. The same division of opinion is true today, and the fact will be emphasized later.

In 1900 Turner † summarized some of the opinions relating to ice erosion as bearing specially on the problem in the Sierras. In the same year Davis ‡ published a review of previous writings on "hanging" valleys with an appended bibliographic list.

References to the literature bearing on the origin of the Great lakes and the valleys and lakes of New York up to 1900 may be found in two publications by Tarr.§

Some references to writings on special areas or particular localities will be given in the following pages.

THEORETICAL DISCUSSION

Burden of proof.—The argument for deep rock erosion by glacial ice is mainly based on analogy, observation showing that glaciers clear their channels, abrade their rock beds, and sometimes modify the form of their valleys. No limit to the amount of such erosion has been determined, and hence an indefinite amount, equal to any requirement, is assumed. The burden of proof has thus been tacitly thrown on opponents of the assumption, and the latter have timidly admitted a doubt or conceded the possibility. The mere admission of the possibility of deep ice erosion gives the argument from analogy full opportunity and places the objector on the defensive. The opponents of the conception have weakly rested in the attitude of defense instead of challenging the production of positive evidence. The phenomena of glaciation are so abundant that the advocates of wholesale glacial erosion should be asked to prove, first, the competency of the agent, and, second, the fact in the particular case.

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*G. E. Culver: "The erosive action of ice." Trans. Wis. Acad. Sci., Arts and Letters, vol. x, 1895, pp. 339-366.

†H. W. Turner: "The Pleistocene geology of the south central Nevada with especial reference to the origin of Yosemite valley." Proc. Cal. Acad. Sci., 3d ser., vol. i, no. 9, 1900, pp. 261-321.

‡W. M. Davis: "Glacial erosion in France, Switzerland, and Norway." Proc. Boston Soc. Nat. Hist., vol. 29, no. 14, July, 1900, pp. 273-322.

§R. S. Tarr: "Lake Cayuga a rock basin." Bull. Geol. Soc. Am., vol. 5, 1894, pp. 339-356.
——— "The physical geography of New York state," 1902, pp. 179, 227-234.

Argument for erosion.—In the absence of a complete theoretical statement of the positive argument for deep glacial erosion the writer will try to supply one, as follows:

(1) Glaciated rock surfaces are proof of abrasion by rock-armed ice. With sufficient intensity of the factors involved and a large time element great effects could be produced.

(2) It has been observed that the ice can "pluck" or grasp and carry away masses of bed-rock.

(3) Glacier ice behaves in a capricious manner, scoring hard rock in some places, overriding and leaving soft materials in other places. This suggests that intensified effects may locally be very great.

(4) The analogy between rivers and Alpine glaciers suggests that glaciers may do excavating work comparable to that of rivers.

(5) The conspicuous milky sediment of glacier waters not only is a proof of mechanical abrasion by the ice, but gives a volumetric measure of that abrasion, often of large amount.

(6) The presence of a large constituent of calcium carbonate in the drift is evidence of large mechanical destruction of the rocks.

(7) The enormous quantity of drift spread over the glaciated areas implies great erosion to supply the material.

(8) The existence of numerous lakes only in glaciated areas proves their relationship to glaciation.

(9) The attitude, form, and structure of many lake basins which lie in the path of former glaciers (for example, lakes Cayuga, Seneca, Chelan) are more readily explained by and argue strongly for glacial excavation.

(10) As some lake basins of the class noted above, under (9), have not been explained by the work of aqueous agencies, it is proper to appeal to ice action.

(11) The occurrence of rock-walled basins marked with ice-scorings, proves that ice does excavate basins. Cirques are admittedly a quarrying work of ice in combination with weathering.

(12) The topographic features known as "hanging" valleys are not recognized as normal product of weathering and stream work, but are well explained by deep ice erosion in the main valleys.

Specific discussion.—To the layman, and even to many geologists, the points presented above would seem to establish a good case for the possibility, if not the actual occurrence, of ice-excavated valleys and basins. They are certainly admirably adapted to serve as the foundation for general assertion and assumption, since their indefiniteness is good defense against direct attack. We will first consider the several points separately and then discuss the matter as a whole.

(1) To produce important erosional effects by abrasion, or the rasping process, exhibited on glaciated rock surfaces, would require a vastly greater length of time than can be conceded. Probably millions of years would be required to accomplish any considerable amount of valley-cutting. The removal of rock by the slow process of glacial abrasion is so ineffective that it is practically a negligible factor in ice erosion. The smoothing, polishing, or sandpapering of rock surfaces is rather an argument against deep erosion, as it is such a slow process that it is inconsistent with great excavation. Its impotency as a factor in valley-cutting is proven by the freshly exposed beds of alpine glaciers where the amount of erosion has been just about sufficient to prove that the ice has been there. And yet these were vigorous glaciers, which have been attacking their channels several thousands of years longer than those glaciers which are assumed to have cut valleys hundreds or thousands of feet deep.

The glacial striæ themselves supply one of the clearest proofs of the slow and ineffective character of abrasion. Cross-striæ are very common phenomena, and may indicate different movements of the ice-body and not merely varying currents. This certainly proves the weakness of the later abrasion, for if general abrasion were such an effective process as to cut hundreds of feet into crystalline rocks during the Pleistocene period the rock should be removed so rapidly that double sets of striæ would be rare phenomena.

The deep groovings and cornice-like flutings, such as shown on Kelleys Island, lake Erie, are by their rare occurrence good evidence of the weakness of glacial erosion. If abrasion were effective, such planing should be common. The curving channels evidently were not wholly made by the ice, and the straight, cornice-like flutings represent some rare combination of special and unusual conditions. It is illogical to use these phenomena as argument for great erosion, as their rarity is proof that the ice did not cut deeply or rapidly as a habit.

Chatter-marks, the crescentric fractures crossing a line of gouging and concave downstream, are also evidence of the ineffectiveness of the glacial plane, not only by their rarity, but by proving that the ice did not hold its tools up stiffly to their work. Roche moutonnée forms prove that the glacier acts as a flexible rasp and not as a plane. The two factors, pressure and rapid flow, which should cooperate in order to produce rapid erosion, do not generally increase together. The reason for this lies in the peculiar mechanics of the glacier, which will be considered later (see page 25), along with a general discussion of the element of abrasion in its wider relation.

(2) "Plucking" is a term which has done much service in the cause of the erosion argument. Doubtless the ice can grasp and pull or push away projecting blocks that have become loosened by weathering or which are much exposed in saliences. The amphitheaters or cirques at the heads of glaciers are thought to be made by the pull of the ice on the frost-loosened blocks, specially in crystalline rocks with vertical jointing. Conditions somewhat similar may exist alongside the stream glacier, but the effect here is to widen and not to deepen the valley. The mechanical conditions at the bottom of the channel or beneath the glacier are entirely different. There the effect of the ice is to abrade away the saliences, and plucking could be only a part of the initial and temporary process of leveling. The idea that plucking has any part in the deepening of large valleys has no warrant in either observation or reason.

An operation analogous to plucking, and which may be included under that term, occurs in the case of bedded rocks which have been weathered so as to produce open or weak horizontal joints. Such lifting of weathered strata is illustrated in plate 23. It can effectively occur only to the depth of weathering, and the discovery of it may be regarded as evidence that the ice has not eroded below the zone of weathered material. This kind of work is more common in case of continental glaciers, and specially along the crests of escarpments or elevations. It is conceivable that a stream glacier might bear such peculiar relation to the attitude of bedded rocks in its channel that, along with exceedingly slow action of water or weathering beneath the ice, it might slowly pluck at its channel bottom; but this is not important, and, as a matter of fact, most of the deep valleys and fiords which have been attributed to ice erosion are in crystalline rocks.

(3) Capricious behavior of the ice within limits may be admitted; but the admission that the ice acts differently under imperceptible or unknown

differences of condition does not justify any claim for extreme erosion. Such claim must be proved by direct evidence.

(4) The correspondence between rivers and glaciers has been exaggerated. It was a valuable idea in the early study of glaciers, while it was necessary to prove that alpine glaciers had motion. To the extent that the glacier has apparent viscosity and flow, the differential movement simulates that of streams; but there the correspondence ends, except that the glacier is in general an aqueous agent, conveying rock rubbish from higher to lower levels. In its manner of erosion, transportation, and deposition, the glacier is quite unlike a river. Its transporting power seems to be equal to any imposed burden; in other words, the glacier is never full-loaded. But the heavy loads of glaciers are not derived from erosion by the ice itself, but are contributed by weathering effects above the glacier, either at the valley head or alongside the valley by atmospheric action on the valley walls. To the extent that glacier-flow obeys the same law as river-flow, the rate of motion at sides and bottom is reduced, and becomes so slow as to be an inconsequential element of erosion during the life of any glacier. In another respect the glacier is unlike the river. In the bed of the latter chemical decay is effective and the river bed is subject to disintegration; and the coarse burden of the river is all carried at the bottom. In the bed of the glacier the disintegrating forces are at a minimum. The work of subglacial streams and the further general discussion will be found later.

(5) The fine rock-dust which gives the milky color to the water from the glacier—the "Gletschermilch"—is admittedly the product of the glacier mill, but it is only partly derived from the abrasion of the bedrock. It is also produced by the grinding of the transported rock rubbish, as is shown by the worn and striated character of the boulders and pebbles in the till. It is optically conspicuous, not for its volume, but because it is so fine that it floats in the water. The argument for rapid glacial erosion, made by Helland, based on the gletschermilch, has been shown by Heim* to be fallacious, and that the large estimates are misleading. He shows that the amount of detritus washed annually from the alpine glaciers is equal to only a small fraction of the amount of detritus carried by the non-glacial streams of the same region. As compared with streams in equal time, glaciers are weak in erosive power. Properly interpreted, the milkiness of the glacier is a proof of its slight abrading effect.

The estimates of the erosion by Muir glacier based on the amount of sediment held in the tidal waters of the inlet can be of little value† for several reasons. The waters of Muir inlet have a depth of 300 feet and a tidal range of 23 feet; this, with the disturbance of the waters and of the bottom sediment, due to the calving of icebergs, makes the amount of sediment held in suspension at the front of the glacier no criterion for the sediment in the glacier drainage. Moreover, even if we had the true measure of the gletschermilch, it would be of no value as a measure of the Muir glacier erosion, since the lower part of the glacier for an unknown distance is overriding gravels. Besides all this is the fact that the sediment washed from this or any other glacier is derived from the grinding of the stones within the glacier as well as the scratching on the bottom, and also from whatever rain and stream-wash there may be on the valley walls.

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*Albrecht Heim: "Handbuch der Gletscherkunde."

†H. F. Reid: "Glacier bay and its glaciers." Sixteenth Ann. Rep. U. S. Geol. Survey, 1896, pp. 454-458.

G. F. Wright: "The ice age in North America," 4th ed., p. 64.

(6) The lime carbonate in the drift is doubtless due to mechanical action on calcareous rocks; but it is inconsiderate and unwarranted to attribute it entirely to abrasion of the channel walls. It represents in the main, probably, the trituration of the limestone fragments which the glacier was transporting, and which had been made ready for the ice-mill by the millions of years of pre-Pleistocene weathering. The great quantities of striated limestone fragments in the drift immediately southward of limestone outcrops show the main source of the carbonate in the till.

(7) The volume of the glacial drift has been cited as the measure and proof of great glacial erosion. This is decidedly untrue and misleading. More justly it is to be regarded as merely the measure of the transportation by the glacier. The mass of drift, no matter how great, is no proof whatever of any erosion at all of sound rock. The assumption fails to recognize the enormous supply of loose material which the ice found ready to its grasp. During the millions of years of the Mesozoic and Tertiary the northern lands were exposed to active weathering agencies under climatic conditions probably similar to those prevailing today in the middle and southern United States. We may well believe that the mantle of geest over all the glaciated areas of the northern hemisphere was fairly comparable to that which covers our southern lands today. This mantle was largely removed from the central areas of glaciation and was piled over the regions where the ice margins lingered. The amount of drift over any glaciated territory is very easily overestimated, and the mental bias of the writer must be noted. For example, the estimates of vast glacial erosion of Scandinavia based on the enormous amount of drift over the German lowlands and elsewhere, and all assumed to be derived from Scandinavia, is most certainly valueless. Morainal belts and valley fillings are the conspicuous masses of the drift and strike the attention, but they are relatively local and should not be taken as typical of the general drift sheet.

It is very difficult to make any quantitative comparisons which would be more than mere guesses, but it seems probable that the whole volume of drift left by any ice body would fall far below a fair estimate of the amount of alluvium, geest, soil, and loosened rock which the ice body found on its territory. In any estimate of the volume of drift we should not fail to add that seized by the rivers and borne seaward, the loess mantle over great areas, and the matter carried away in solution.

It will generally be found that the expert students of the drift make the more moderate claims for its volume.

(8) The occurrence of tens of thousands of lakes in the glaciated areas is a striking fact when placed in comparison with their rarity in southern districts. There is no doubt of their being related to glaciation. The physiographic explanation is that they represent the infantile and youthful stages of the reconstructed drainage left by the interfering ice sheet. The geologic explanation is that they are chiefly morainal—that is, they occupy depressions in the irregularly piled drift or lie in valleys which are blocked by drift fillings. Some of the lakelets are in shallow rock-basins, which will be considered later.

Some of the larger lake-basins, like those of central New York, are complex in their form, structure, and relations and are not readily or positively explained as to their precise origin or genetic relationship without sufficient deep borings to show the preglacial topography. The slopes of some of these valleys have been smoothed by the glacial rubbing, and it is not surprising that they were once thought to be the product of glacial excavation. Naturally those valleys which lie in the direction of the glacial flow have been most modified by the ice action. That the ice has smoothed the valley slopes to some extent and swept away the talus accumulations and other loose materials is very probable, but to claim more than this for the ice-work is an assumption without any sufficient basis in geologic facts. The subject is discussed on pages 55–65.

(9) and (10) Because some of the Swiss and Italian lakes, and the "Finger" lakes of New York could not be at once fully explained in the causality of their attitude, depth, form, relation, etcetera, under non-glacial agencies, they have been regarded as illustrations of deep glacial erosion. Such lake-basins were, indeed, the first suggestion, and have been one main argument, for extreme ice erosion. Even recently some physiographers appeal to glacial action and postulate a thousand feet of cutting by ice because their rules and principles of topographic evolution do not immediately explain the peculiarity of the topography. Tacitly, it has been expected that one denying the theory of ice-cutting must disprove it; but the burden of proof belongs on the advocates of ero-

sion, who should first prove that it is even possible for a glacier to cut a valley or large basin somewhere, some time, or under some conditions. There are no facts of observation from any living glaciers, nor from any dead glaciers, which justify the idea that they can cut valleys or deep basins in live rock. The sufficient negative proof is given below.

(11) There seems to be sufficient testimony to the occurrence of small or shallow rock-basins, in crystalline rocks, in the central areas of glaciation; also in cirques or valley heads; and perhaps in the course of mountain valleys at the foot of steeper slopes. Shallow basins in crystalline rocks are to be expected, as a product of rock-weathering and glacial removal of the loosened material. This was recognized long ago by Pumpelly.* Because a rock-rimmed basin is found to bear glacial striæ on its borders the conclusion does not necessarily follow, logically, that the basin was cut out of the solid rock by ice erosion, although this is commonly assumed. The striæ merely prove that glacial ice has passed over the rock. However, since weathering and stream action do not normally produce basins, it is a legitimate theory that ice really had some function in the forming of the basins; but since there is abundant proof from living glaciers that ice does not cut basins out of solid rock as a habit, it is much more reasonable and scientific to conclude that the ice has usually only developed a structure or form partly due to differential weathering.†

The production of small or shallow rock-basins in mountain valleys may be fully admitted without really touching the problem of large lake basins like Chelan or Cayuga. Both quantitatively and in principle the genetic process is entirely different. For example, a river can excavate a plunge-basin at the foot of a cataract, but this gives no warrant for assuming that the river can cut a great basin in its graded valley by its ordinary flow.

The same statement applies to cirques.‡ These are a product of an exceptional process of quarrying, due to combination of frost-work and ice-pull at the bergschrund or along deep crevasses. The principle has no application to ice abrasion beneath the glacier in its ordinary flow. The forces involved in cirque-making may have some play alongside the glacier in the process of valley widening, or in the production of the theoretical U-form of glaciated valleys.

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*R. Pumpelly: "The relation of rock-disintegration to loess, glacial drift, and rock-basins." Amer. Jour. Sci., vol. 17, 1879, pp. 133–144.

†It is desirable that reliable observations should be directed to the determination of the question whether undoubtedly glaciated rock-basins occur in sedimentary rocks.

‡For the study of cirques consult specially the following:

W. D. Johnson: On cirques. Science, new ser., vol. ix, pp. 112–113.

F. E. Matthes: "Glacial sculpture of the Bighorn mountains, Wyoming." Twenty-first Ann. Rept. U. S. Geol. Survey, 1899–1900, pt. ii, p. 167, et seq.

H. W. Turner: "Pleistocene geology of the south central Sierra Nevada, with especial reference to the origin of Yosemite valley." Proc. Calif. Acad. Sci., 3d ser., Geol., vol. i, p. 289, et seq.

A. C. Lawson: "Geomorphogeny of the upper Kern basin." Univ. of Calif. Pub., Bull. Dept. Geol., vol. 3, 1904, no. 15, pp. 291–376. (Particularly page 358.)

(12) " Hanging " valleys have been the occasion in later years for postulating deep valley-cutting by stream glaciers. The assumption is made of valley deepening in hard, crystalline rocks, of hundreds and even thousands of feet, simply to explain a discordance of valleys. The physiographic argument is based, in turn, on another assumption, that mountain valleys, as those of Norway and Alaska, the Alps and Sierras, should, under atmospheric and aqueous agencies, be graded to an accordant system. With the highest personal regard and admiration for the masters in physiographic science who have advanced the above ideas, the writer yet believes that their conclusions are wrong. The genesis of topographic forms involves a number of agencies which in their relative effects are indeterminate. The students of these very theoretical and complex problems should not expect to find the full explanation at once for all puzzling features ; neither should they resort to short cuts which are mere assumptions. Discordant valleys will be found to have some rational explanation in non-glacial processes, probably as a natural stage of drainage under exceptional conditions. The assumption of enormous ice excavation does not seem warranted. The further discussion of this in reference to certain mountain districts and to central New York topography will be found later in this paper.

General negative argument.—Several elements or factors involved in the mechanics of glaciers are decidedly unfavorable to great erosion, and none are positively favorable. From the study of glacial phenomena for fifty years the following principles of glacier physics seem to be well established :

(*a*) In the ordinary normal flow, the upper part of the glacier moves faster than the lower or bottom portions. [*]

(*b*) The fluency of the ice diminishes in proportion to the amount of commingled rock-debris. [†]

(*c*) Horizontal shearing occurs, the upper, more rapidly moving, layers sliding over the lower, basal, and laggard layers. [‡]

(*d*) The typical form of the ice-eroded channel is U shape, as compared with the V form of youthful stream channels. Glaciers, therefore, widen their valleys. [§]

(*e*) The condition of load most favorable to abrasion is a light charge of coarse and hard rock fragments. [||]

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[*] H. F. Ried : " The mechanics of glaciers." Jour. Geol., vol. iv, 1896, pp. 912-928.

[†] I. C. Russell : " The influence of debris on the flow of glaciers." Jour. Geol., vol. iii, pp. 823-832.

[‡] H. F. Reid : Jour. Geol., vol. iv, pp. 920, 925 ; I. C. Russell : Jour. Geol., vol. iii, pp. 823-832 ; G. H. Barton, Tech. Quar., vol. x, p. 220 ; Chamberlin and Salisbury, Geology, I, p. 302.

[§] W J McGee : "Glacial cañons." Jour. Geol., pp. 350-364.

[||] I. C. Russell : Jour. Geol., vol. iii, p. 823-832 ; Chamberlin and Salisbury, Geology, I, pp. 271, 273.

It is evident that any deepening of glacial channels must be chiefly by abrasion, and that this must be proportionate to the two factors of velocity and pressure, other factors remaining uniform. With this in mind, let us briefly consider the accepted principles enumerated above.

The slower movement at the bottom of the glacier causes a corresponding reduction in one of the factors of abrasion. The reduced rate of flow may be due to either of the three causes noted above (*a*, *b*, *c*,) or to all combined, and the reduction by a heavy load of debris and by shearing may amount to practical stagnation. We find here a most important principle in its bearing on deep erosion. Rapid corrasion by the ice is a self checking process. To the degree that the bottom ice is receiving rock debris, either by its own wear or otherwise, its flow is checked, while at the same time the subglacial rubbish serves as a shield and protection to the bed-rock. The product of abrasion is a rock-slime, which has in itself no helpfulness in erosion, but serves instead as a lubricant to prevent erosion. It seems impossible for the rock-flour to be removed as rapidly as produced, if produced in large amount. Its production is inconsistent with free circulation of water beneath the ice, and the estimated rate of bottom melting, due to earth heat, amounting to one-fourth of an inch per year, can have no important effect in washing away debris. The advocates of enormous erosion are requested to answer this question: If any glacier sawed down its bed " thousands of feet " during Pleistocene time, how did the saw clear itself for continuous cutting?

The checking of erosion by its own product implies that abrasion should be freer near the head of the glacier and diminishing toward the end as the subglacial load increases. This agrees with observation and contradicts the ice-erosion theory for the Swiss lakes and the Norwegian fiords, where it is claimed that the ultimate sections of the valley are the deeper.

Two more elements connected with the abrasion by the glacier are of interest and importance here. These are the apparent viscosity and the practical rigidity—two contradictory principles which seem, nevertheless, to act together.* To the degree that the glacier moves as a rigid mass or bolt or plane its effectiveness is gone when its bed has been smoothed so as to offer little resistance to the ice plane. To the degree that viscosity is effective the abrasion is lessened by the failure of the ice to hold its cutting tools up rigidly and effectively to their work. Both elements are unfavorable to unlimited erosion.

The work of the ice plane is rarely illustrated by straight groovings, as discussed above on page 19. The viscous or plastic habit is more commonly proven in glacial phenomena. The students of glaciers in Switzerland, Greenland, and Alaska have recorded many observations which show the yielding of the ice to obstructions by arching over them or bending around them. The production of roche moutonnée in the beds of glaciers is an illustration of its yielding habit and its adaptation to the irregularities of its bed. The rounding and smoothing of the rock bosses is proof of the polishing action of the glacier, but the existence of the bosses is proof that the abrasion was not sufficient to remove them or to level the bed. The ice could not remove one set of original irregularities in its bed and then produce another set. If the ice could undo its own work, or act as a plane at one time and then in the same place scoop out irregularities and make mounds in its bed, we should find the roche moutonnée form as the common form of glaciated surfaces even in soft materials, whereas the form is characteristic of hard rocks and is doubtless produced by a moderate amount of scouring on weathered rocks. Other writers have recognized that the roche moutonnée form is not consonant with vigorous abrasion or planation by the ice, but, on the contrary, proves relatively slight abrasion.

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*The latest discussion of this complex and much disputed problem is in Geology, I, by Chamberlin and Salisbury, pp. 294–308.

Drumlins illustrate on a vastly larger scale than roche moutonnée the same yielding habit of the ice. Whatever be the source of the drumlin material, their form is due to overriding by the ice and the rubbing and molding by ice flow. They prove not only failure of erosion at the locality of their occurrence, but failure of transporting power. They are large examples of the compliance of the marginal ice of the continental sheet.

The question might be asked, Could not a very deep glacier, having great pressure on its bed, along with a steep gradient, giving high velocity, rapidly abrade its bed ? The reply is, decidedly no ! The postulated conditions can not occur together, except within ineffective limits. Extreme depth with high gradient is an impossibility in rivers and in glaciers. As a matter of fact, the glaciated valleys are not extremely steep for mountain valleys, and the upper and steeper sections often show little erosion (see description of Alpine phenomena, page 31). The great deepening of valleys has been assumed for the lower or ultimate sections (in case of the Finger Lake basins the cutting is assumed where the ice tongues were moving *up* the valleys). The physical conditions at the bottom of deep glaciers is not known inductively. It is believed that their bottom temperature is constantly at the melting point, which favors fluency and the yielding of the ice, while the slow melting tends to keep the rock debris beneath the ice, where it acts as a buffer. Moreover, increasing depth and pressure must tend, other conditions remaining the same, to diminish motion at the bottom.

Shearing of the upper and more rapidly moving layers of the glacier ice over the lower, basal, and laggard layers seems to be established by observation. To whatever degree this factor is active it diminishes the velocity factor at the bottom of the ice and antagonizes erosion. It must be more effective where the bottom ice is obstructed. It argues specially against the flow of ice at the bottom of basins, and implies that the ice resting in a basin is likely to form a bridge over which the upper ice can travel. This is an important point with reference to the assumed glacial origin of lake basins.

The mechanics of ice flow in basins has been well discussed by Culver (pages 363, 364 of paper cited on page 17). His conclusions, adverse to basining erosion, are certainly sound for the open, graded sections of valleys. The most effective abrasion must be on the rims of the basins, the tendency of which is to obliterate the basin rather than to make it, except, perhaps, at the foot of a steep slope.

The U shape of ice-worn channels is generally accepted as of diagnostic value. Like other physiographic features, it may be indefinite and liable to different interpretations by different observers, and the psychologic equation must not be forgotten. The U form belongs to stream valleys in a stage of their development. But such stream valley when scoured by ice is so much more striking, because of its uniformity and smoothness (just as a drumlin is more noticeable than a hill of the same general shape but of uneven surfaces), that it has been assumed as peculiar to ice erosion. Probably in many cases the ice has done nothing more than to clear the preglacial valley of its talus and other accumulations and to give the conspicuous smoothed surfaces. The accordance of the glaciated U-shaped sections of mountain valleys in their general proportions and their grade with their unglaciated extensions prove that the amount of ice erosion has not been great; but to whatever extent ice erosion has occurred the U form implies that it has included *widening* of the valley. Some glacialists have concluded from field study that glaciers tend to widen their valleys much faster than to deepen them, and the analysis of the mechanics of the glacial stream flow leads to the same conclusion. No critical study, so far as the writer is aware, has reached any different conclusion.

It is not believed possible for a glacier to deepen its valley to any appreciable extent without corresponding increase in width. The reasons for the more rapid widening of the valley are not difficult to find. It is not conceived as possible that "plucking" or quarrying or any other mass-erosion can occur at the bottom of a glacier, under the great pressure, after the saliences are planed off and the rock surface has been smoothed. The only possible wear at the bottom is the slow process of abrasion. But alongside the glacier the forces of rock-destruction are greater in number and intensity. It has been shown that the combined resultant of the several erosive factors in stream glaciers—weight or pressure, slope of channel or velocity of flow, and friction on the sides and bottom of the channel—is most effective along the sides of the glacier, and in addition to this we also recognize along the glacier edge the cooperation of weathering, and of frost-work, suggesting that at the bergschrund. The products of erosion are more or less removed from the plane of contact along the glacier edges and carried downward toward the bottom (to burden the bottom ice and there prevent erosion), while new tools of marginal erosion are constantly supplied by land-wash and from the lateral moraine.

Probably the most important and conclusive paper in English relating to the mechanics of glaciers with reference to their erosional work on their channels was published in 1894 by W J McGee,* reasoning from studies in the Mono Lake region. His general conclusion is summed up in the last sentence of his paper :

> "It follows that these features do not necessarily imply extensive glacial excavation or indicate that glaciers are superlatively energetic engines of erosion."

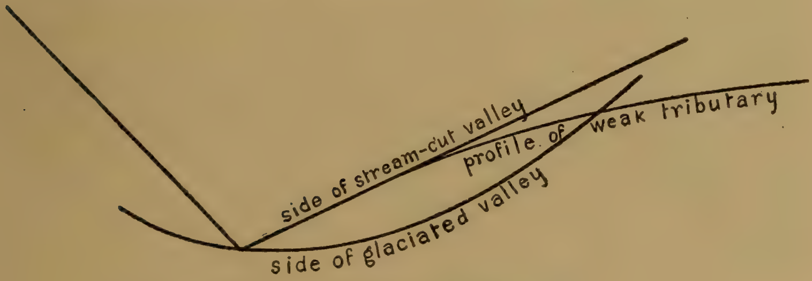

FIGURE 1.—*Truncation of Tributary Valleys.*

This theoretic diagram illustrates possible truncation of tributary valleys by glacial widening without deepening of the main valley.

Some of the special and positive results of his analysis are stated in more positive terms, as follows :

> "It follows that the general tendency of glaciers must be to widen rather than to deepen the valleys they occupy, and to transform V to U canyons. . . . It follows again that the characteristic glacial canyons must be only modified stream-canyons" (page 359).

He shows that one effect of changing a V-shaped valley to U shape is to cut off the lower or terminal part of the convex profile of the smaller tributary and ungraded valleys, and to thus produce what have been called "hanging" valleys. Figure 1 is his figure, somewhat modified. The words of his conclusion on this point are as follows:

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* W J McGee : "Glacial canyons." Jour. Geol., vol. ii, 1894, pp. 350-364.

> "It follows that the second feature ('hanging' valleys) of the typical glacial canyons may naturally result from temporary occupation of water-cut canyons by ice, and that it does not necessarily argue profound glacial erosion" (page 360).

From this physical analysis he recognizes the possibility of some basining erosion:

> ". . . Thus the excavations of depressions by direct ice-action has a definite though indeterminate limit, and can probably never exceed a moderate fraction of the depth of the ice . . ." (page 362).
>
> ". . . The irregularities of gradient peculiar to such canyons are not greatly intensified, while glaciated rock basins are comparatively rare and of slight depth. It equally follows that the occupation was only temporary and the sum of glacial erosion relatively inconsiderable" (page 363).

These conclusions of Doctor McGee adverse to ice erosion are specially significant because they are based on merely the mechanics of the glacier as a plastic, moving body, taking into account weight, slope, friction, and the potential energy available for mass motion, or the downstream impulse and weight at any point, constituting the intensity at that point. It should be clearly understood that this analysis does not take into account at all the important adverse factors due to the effect of the accumulating subglacial drift burden. The problem is treated as if the glacier had the power of constantly clearing its saw-cut.

As a general conclusion it may safely be held that without glacial widening of a valley there can be little deepening. This is a very important principle and can be effectively applied in special cases (see page 40).

From whatever side we attack the problem of glacial erosion the physical and geologic study leads to the conclusion that all the erosion factors are restricted or limited in their effectiveness. All the evidence from observation and direct study of living glaciers and all the theoretic conclusions derived by sound reasoning from known phenomena lead to the confident judgment that stream glaciers commonly act on their beds as flexible rasps. Rarely or locally they act as rigid planes. In either case their erosive effect is either limited or exceedingly slow. They scratch and polish their rocky beds, and to a limited extent they widen their channels.

If the glaciers were given unlimited time of millions of years they might accomplish considerable cutting by the slow rasping process; but their work would lag far behind that of rivers. Any claim that they can possibly cut faster than rivers is an untenable assumption. Their transporting power is greater, mile for mile, but in equal time the river carries many times more material. Like the river, the glacier is not burdened by the product of its own corrasion, but by the material which other agents have given it. It is certainly true that rivers are the only valley makers. We have no evidence that any glacier has ever carved its own valley; nor have we any proof that any glacier has greatly deepened the valley it has occupied, notwithstanding the many assertions, even in the text books.

The above positive and rather dogmatic statement is confirmed by all the observations on the phenomena of both living and extinct glaciers. The Pleistocene glaciers have recently abandoned their channels and have left us hundreds of examples of their work. Most living glaciers are waning rapidly and exposing their recent work. In no case has there been found any conclusive proof of valley making or of basin making in rock; but, on the other hand, there is a wealth of positive and incontrovertible evidence that the ice has not seriously eroded its bed. The quite unanimous testimony of geologists who are most familiar with living glaciers is to the effect that they do almost no erosional work, or scarcely more than sufficient to attest the fact of their presence. Yet the glaciers of the Alps were at work during all the life of the Pleistocene glaciers, which are assumed to have cut valleys "thousands of feet" deep in granitic rocks, and they have continued to work for some thousands of years longer and should show proportionately better results. They show very little erosive effects. Plates 12–15 illustrate obstructions and irregularities in the beds of what have been vigorous glaciers of the Alps, and similar examples can be indefinitely multiplied, and doubtless from other fields. But wherein do the stronger glaciers of the Alps differ in size or principle or function or effect from those of the Sierras or Cascades or Alaska or Norway?

CONCRETE ILLUSTRATIONS

Alps.—Apart from a group of eminent physiographers, the geologists and alpinists who are familiar with the glacial phenomena of central Europe are practically unanimous that glaciers are not effective agents of erosion. The argument was traversed by Albrecht Heim in his "Handbuch der Gletscherkunde."

The continued retreat of the Alpine glaciers is now exposing sections of their beds which have never been visible before and which are pertinent evidence in this discussion. If any valleys in Switzerland, Norway, or elsewhere could have been greatly deepened by Pleistocene ice, it is very strange that active glaciers, working thousands of years longer, should have left obstructions and irregularities in their beds, as shown in plates 12–15.

The end of the Unter Grindelwald glacier (plate 12) lies wedgingly in a chasm of rock cut by water—probably subglacial. It convincingly shows the failure of the glacier to effectively erode its bed, and all the rock forms at and below the end of the glacier give the same evidence of the glacial impotence. The walls of the valley have been merely sandpapered, and the same condition is practically true of all the glaciated valleys of the Alps. The accompanying plates give a few illustrations from several fields of the Alps. These facts are commonplace to Alpine geologists. It is an easy reply for the physiographic erosionists to say that the various conditions of erosion in the Alps were unlike those of Norway or the Sierras; but the burden of proof is on them to show the practical difference.

The valleys of the Aare* and the Ticino† have recently been described, from a physiographic standpoint, as showing great glacial erosion. The writer recently walked through the Aare valley above Meiringen (the Haslethal valley) and over the Grimsel, and passed by rail up the Ticino, and saw only evidences of the absence of great ice erosion.‡ The Aare valley is described by Brigham as having a series of expansions and constrictions, which fact alone would seem to positively rule out great enlargement by a valley glacier. The cliffs at Grimsel are only smoothed by abrasion. In old photographs the rocks at the narrow gorge of the Aare, by the Grimsel hospice, appear to show glacial scorings passing up and over the cliffs. But this is deceptive, for on the ground it is seen that the striæ are nearly horizontal and the abrasion was not sufficient to obliterate the irregularities and the surfaces due to jointing (plate 14). The jointing approaches the vertical, and the smoothed joint surfaces give at a distance the false appearance of nearly vertical ice scorings.

The discussion appended to Brigham's brief paper referred to above contains the gist of the whole contention, and the explanation and argument by Turner adverse to ice erosion has not been answered, and is believed to be unanswerable.

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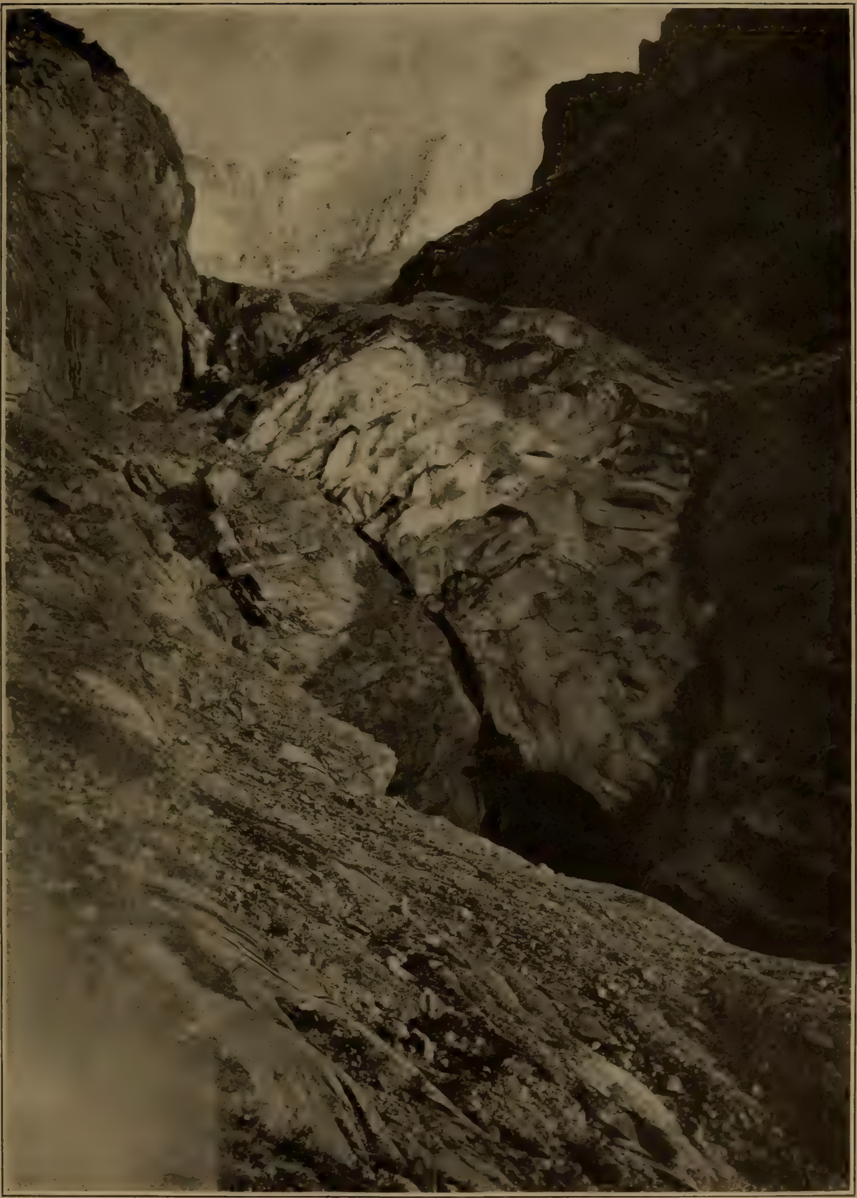
* A. P. Brigham: "Glacial erosion in the Aare valley." Bull. Geol. Soc. Am., vol. 11, 1899, pp. 589–592.

† W. M. Davis: "Glacial erosion in the valley of the Ticino." Appalachia, vol. ix, 1900, pp. 136–156; "Glacial erosion in France, Switzerland, and Norway." Proc. Bos. Soc. Nat. Hist., vol. 29, 1900, pp. 273–322.

‡ When the writer visited the Alpine valleys the descriptions referred to were not in mind, and the problem of glacial erosion was in mind only incidentally. The observations noted and the photographs taken were without any intention of discussion as to the origin of the valleys. This fact is given in justice to the argument of this paper, and at the same time it illustrates how physiographic features are subject to very different and even opposite interpretations according to the mental attitude of the observer.



TERMINATION OF UNTER GRINDELWALD GLACIER

The end of the glacier now hangs suspended in a narrow gorge, evidently the work of subglacial waters. The abandoned valley bottom is exceedingly irregular. August, 1903

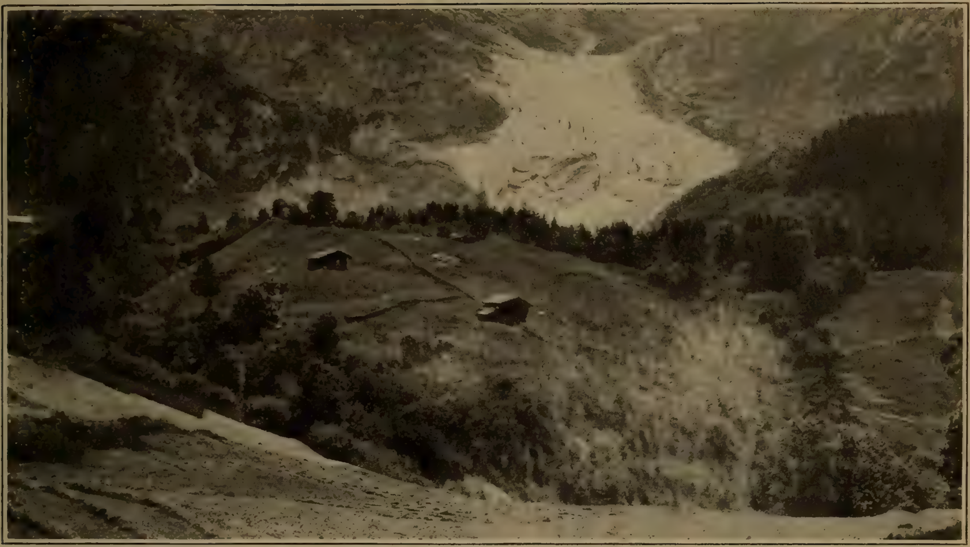


FIGURE 1.—OBER GRINDELWALD GLACIER

An angular mass of rock appears, by the waning of the glacier, in the middle of the valley. The chalets in the foreground are on an ancient moraine. August, 1903

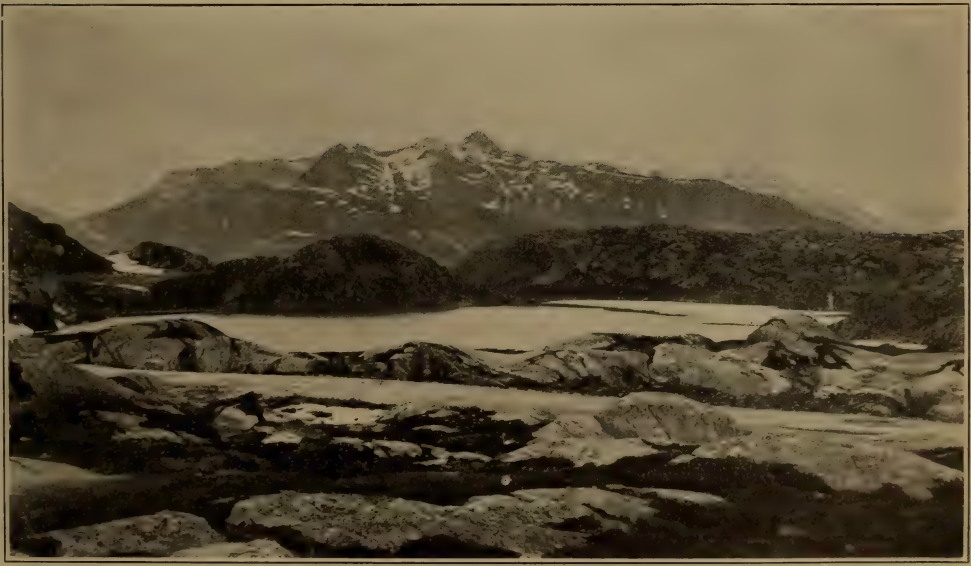


FIGURE 2.—SUMMIT OF GRIMSEL PASS AND TODTENSEE

A heavy flow of ice once swept across this col, but the bosses of rock are merely rounded. August, 1903

GRIMSEL SUMMIT AND OBER GRINDENWALD GLACIER

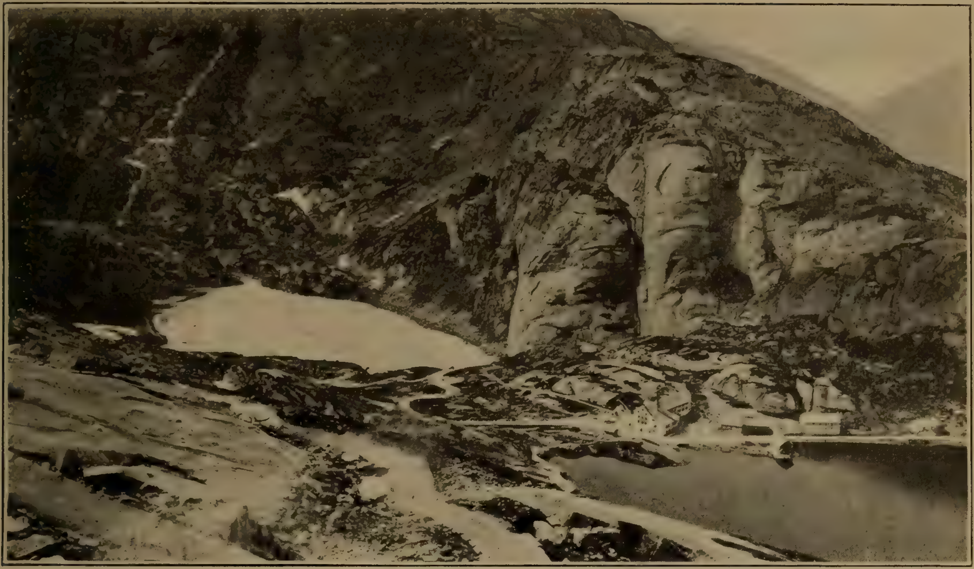


FIGURE 1.—CLIFF AT A SHARP TURN IN THE AARE VALLEY

Where this cliff lies ice erosion should have been most pronounced. The projecting masses are merely rounded. July, 1903

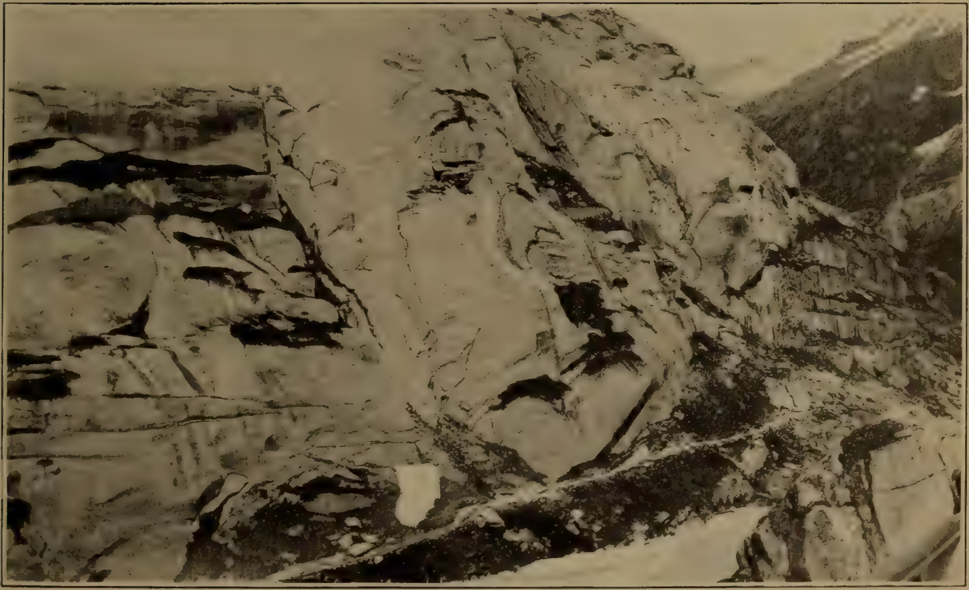
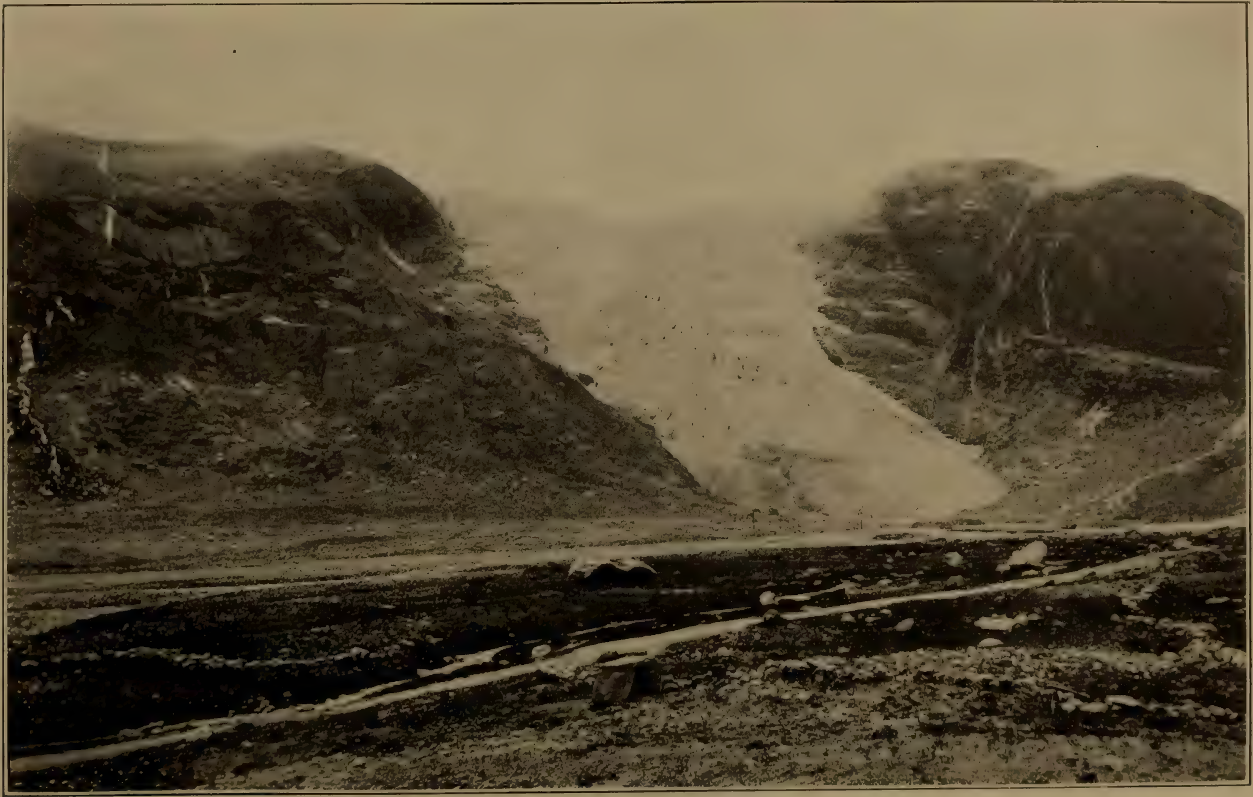


FIGURE 2.—NEARER VIEW OF CLIFF IN FIGURE 1

Showing horizontal abrasion. July, 1903

GLACIATED CLIFF NEAR GRIMSEL LAKE AND HOSPICE



RHONE GLACIER

The recession of the ice reveals a "hanging" valley in the main course of the glacier. July, 1903

Norway.—To several of the geologists of Norway* the very striking topographic features of that country have seemed to require glacial erosion, and recently Professor Davis has favored the same conclusion. In the paper noted on page 32 he says:

> ". . . Hence glacial erosion must under this supposition be appealed to for the widening of preglacial canyons, steep-walled and narrow, into the existing fiord troughs, steep-walled and broad. At the middle of the fiord troughs the lateral erosion thus demanded would often measure thousands of feet, and that in the most massive and resistant crystalline rocks."
>
> ". . . Hence to develop the existing discordant valley system from a mature preglacial valley system of normal river erosion requires a great deepening of the fiords by ice action, again to be measured by thousands of feet. Thus there seems to be no escape from the conclusion that glacial erosion has profoundly modified Norwegian topography." (Page 290.)

It should be noted that Professor Davis does not unequivocally assert that the fiords have been deepened thousands of feet, but the next maker of a text-book may use it as a positive and conclusive statement.

Doubtless the fiords are difficult of immediate and precise explanation by stream work. They have recently been occupied by glaciers, and it was not unnatural to appeal to them as the cause of the deep valleys and the discordance. The whole argument is based on the physiographic features, and implies glacial cutting of thousands of feet in the hardest crystallines. The conception certainly ignores the facts of observation, which show the impotency of ice-work. The Norwegian glaciers were of the alpine type, and there is no reason for attributing to them any special property or power.

Scotland.—The British geologists, even those who follow more or less the lead of Ramsay in the belief in ice erosion, have not appealed specially to their own physiography. But a recent paper† requires brief notice, because it has been quoted in this connection (page 51).

This paper is a description or reference to features of topography and drainage in Scotland which seem to the author to be due to ice action. The paper is far from convincing. The statements are too general, too theoretical, too discursive, and too largely assertive. No maps or other illustrations of any kind are given. Apparently the author sees evidence of ice-cutting which expert glacialists have not seen, for if the features possessed the clearness and significance which he attaches to them they should have been thoroughly described long ago. The doubt concerning the matter of this paper pertains to much of the physiographic evidence. There is so much indefiniteness and genetic complexity in features of topography that interpretation has unusual latitude. The attitude of mind and the theory of the observer count for much more than in most other lines of study, and the arguments, conclusions, and assertions are often difficult to either verify or deny, although doubt may be very strong.

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* Most of the literature is foreign, but the facts and discussion may be found in Heim's "Handouch der Gletscherkunde," in the paper by Davis, noted on page 32, and in an article by Andr. M. Hansen, Jour. Geol., vol. 2, pp. 123–143.

† J. G. Goodchild: "Glacial furrows." Geologists Magazine, vol. iv, pp. 1–7, June, 1896.

Greenland.—During the past decade Greenland has been the Mecca of the glacialists, and among those who have visited the land and published their observations are Barton, Chamberlin, Heilprin, Nansen, Peary, Salisbury, Tarr, and Wright. The writings of all these men practically agree on the following points: That the West Greenland glaciers are carrying but little drift, and that mainly in the basal layers; that erosion is slight; that the exposed topographic features are not the product of ice erosion; that the lower layers of the ice show reduced movement, with some shearing of upper over subjacent layers; the overriding of boulders and other obstructions; the overriding by the edge of the ice of its own moraine deposits; and the comparative absence of clay or rock-flour.

It will not be necessary to refer at length to the literature,* as fortunately there is no essential divergence of opinion over the fact of slight ice erosion.

More than any other writer on the Greenland glaciers, Professor Tarr has referred to the erosional phenomena, and has particularly and emphatically noted the failure of the ice in that respect. This is the more significant as Professor Tarr has been one of the American advocates of ice-eroded valleys. A few lines quoted from his writings will be pertinent.

> "Although the hills of Turnavik (eastern margin of Labrador) are well rounded, and show signs of decided ice scouring, . . . it is evident that the glaciation did not succeed in destroying even the details of the preglacial topography. . . . This evidence of slight scouring is in harmony with that found in Baffin land and Greenland, and also in parts of New England. It shows that preglacial decay was deep, and that the general ice scouring did not lower the surface far below the zone of decay in the weaker members of the rock series." (Am. Geol., xix, 192.)
>
> "Very nearly the same conditions were present in Cumberland sound, though the details of the preglacial topography are perhaps even more perfectly preserved. The surface of the hills is extremely irregular, and valleys and ridges of minute size, distinctly of preglacial origin, abound. . . . It was astonishing to find how little effect in smoothing the surface was accomplished by the ice invasion of the

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*The writings of Professor Chamberlin are to be found in a series of articles in the Journal of Geology, vols. ii, iii, and iv, and in the Bull. Geol. Soc. Am., vol. 6, pp. 199-220.

R. D. Salisbury: Jour. Geol., vol. iii, pp. 875-902; vol. iv, pp. 769-810.

G. H. Barton: Tech. Quart., vol. x, pp. 213-244.

R. S. Tarr: Amer. Geol., vol. 19, pp. 131-136, 191-197, 262-267; vol. 20, pp. 139-156. Bull. Geol. Soc. Am., vol. 8, pp. 251-268.

A. Heilprin: Pop. Sci. Monthly, vol. 46, pp. 1-14.

land; but very nearly the same conditions exist in those parts of the Greenland coast, which were studied in detail. It is noticeable near Cumberland sound, as well as in Turnavik, and in Hudson's strait, and indeed in Greenland, that there are many basins of small size, surrounded entirely by rock. While some of these have no doubt been scoured out by differential ice erosion, the position of many of them, along the line of weaker rocks, indicates that they represent differential preglacial weathering. The advance of the ice in these cases has served to remove the decayed rock, and perhaps to deepen the depressions formed by this action, though ice erosion would not in this case be the prime cause of the basin." (Ibid., 195.)

"In other words, the irregular surface (of rock) is made more regular by the nearly stagnant bottom ice, which fills the depressions. . . . The ice arches over the irregular land, making curves, which are plainly seen by the arch of the debris layers, whose form is that of a generalized dome of a regular form. . . . Some areas are scoured more than others, and there is a gradual reduction to a generalized surface because the depressions are protected by more nearly stagnant ice. while the projections are worn down toward the curve of average outline of the irregularity."

If there is any reason why the ice should have less erosive power in the Greenland region than elsewhere it has not been found. Possibly there is some explanation in latitude; greater rigidity of the ice, due to low temperature, might facilitate shearing and reduce plastic flow at the bottom. It is also possible that the Greenland ice cap is not very old and has not been very active; but, whatever explanation be forthcoming, the Greenland phenomena give only decidedly negative evidence on the question of deep ice erosion.

Sierras.—It was formerly believed by a few geologists that the deep valleys in the Sierras, including the Yosemite, had been excavated by glaciers. At present probably no one holds such view; but opinions quite as radical and probably just as mistaken are still held for other regions; hence it will be pertinent to review the Sierran phenomena for comparison. Among many writings, we will note only a few which bear specially on the glaciation.

In 1891 Becker * published a paper on the structure of the high Sierras between Truckee river and the south fork of the Stanislaus, in which his argument and conclusion were most emphatically opposed to great ice erosion. He says:

"Some few geologists still believe that glaciers . . . vigorously erode solid rock. In my opinion, this theory is maintained in opposition to overwhelming evidence. Reference has already been made to some of the many facts indicating a trifling amount of erosion since the preglacial date in the higher part of the Sierra, and long before my examinations Professor Whitney reached the conclusion that the solid rock had been scoured rather than eroded by glaciers." (Page 65.)

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*G. F. Becker: The structure of a portion of the Sierra Nevada of California. Bull. Geol. Soc. Am., vol. 2, 1891, pp. 49–74.

> "Ice seems to have played a considerable part in clearing the canyons of fragments and in excavating shattered and decomposed patches, so that in a sense one must ascribe a large erosive effect to the glaciers; but the ice seems, nevertheless, to have been incapable of cutting into solid masses to any extent, or even into much fissured rock where little decomposition had preceded and where the blocks were tightly wedged together.
>
> "In many cases the glaciers have polished rock surfaces, the contours of which are so thoroughly characteristic of surface exfoliation, due to weathering, that no observer could doubt their character, and some of the surfaces are such that ice could not possibly have modeled them. Such evidence, together with that derived from the occurrence of glaciated lavas near the bottoms of the present canyons, indicates very clearly that the present system of canyons was established long before glaciation began, and probably during the warm and no doubt very wet Pliocene epoch." (Page 68.)

From study of the canyons in the region about lake Mono, Russell* concluded that they were not the product of ice erosion, and Gilbert† agrees with all the other experts that the present drainage features of the Sierras were far advanced before the ice occupation.

The important theoretical paper on glacier mechanics, already quoted (page 29) as adverse to extreme erosion, published by McGee in 1894, was an outcome of his work in the Sierras.

In 1900 a critical and important paper was published by Turner‡ on the south central Sierras. In this paper he gives an excellent review and discussion of the problem of ice erosion in application to the Sierras, and Yosemite in particular, and proves conclusively that the canyons, including Yosemite, were not made by ice, although he recognizes slight glacial action in valleys where it had not previously been noted.

Regarding rock basins, Turner states that such are abundant in the glaciated Sierras, and ordinarily in granite, and says:

> "Many of these rock basins are at the base of steep slopes, and it is possible in such cases that the great downward pressure of the ice excavated such basins, especially where the rock was much jointed. The location of other rock basins, however, although always where the ice mass appears to have been very thick at one time, is such as not to suggest the probability of there having been sufficient weight of ice to scoop out a basin in hard rock. . . . It is more than likely that in many such cases the basin was originally produced by unequal disintegration of the granite in preglacial time, this decomposed material being subsequently excavated by the ice." (Pages 286, 287.)

Some of the rock basin lakes are more than a mile long and toward 100 feet deep. Lakes Washburn, Tenaya, and Johnson are mentioned.

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*I. C. Russell: "Quaternary history of Mono valley." Eighth Ann. Rep. U. S. Geol. Survey, pt. i, 1889, p. 352.

†G. K. Gilbert: "Lake Bonneville." Monograph i, U. S. Geol. Survey, 1890.

‡H. W. Turner: "The Pleistocene geology of the south central Sierra Nevada, with especial reference to the origin of Yosemite valley." Proc. Calif. Acad. Sci., iii ser., vol. i, no. 9, 1900, pp. 261-321.

Professor J. C. Branner* has shown that the singular topography about the cataracts in the Yosemite valley was produced by the more rapid down-cutting by the streams draining the glaciers than by the ice itself. He says:

> "The evidence of the falls at the mouths of the hanging valleys shows that the wearing done by the ice was trivial compared with the wearing done by the glacial streams. The subglacial streams also cut channels beneath the ice a great deal faster than the ice cut the broader floors on which it moved." (Page 551.)

The latest paper is by Lawson,† on the upper Kern valley, in the high Sierras, a very interesting description of a most remarkable valley and region:

> "The canyon of the upper Kern is one of the great canyons of the Sierra Nevada, and in some respects it is the most remarkable of them all. . . . But while it is a feature essentially due to stream erosion its characters as such have been modified by its having been occupied for a time by a long trunk glacier, which extended down the canyon as far as the mouth of Coyote creek and which was fed by several tributary glaciers. . . . In consequence of this episode in its history the canyon above Coyote creek has the typical U shape in cross profile so characteristic of glaciated mountain valleys." (Pages 328, 329.)
>
> "The width of Kern canyon below the Kern-Kaweah river does not appear to have been appreciably increased by the occupation of the ice. This is practically proven by the following consideration: The depth of the ice in the canyon averaged probably not more than 1,200 feet. The walls of the canyon are about twice this height, and the lateral recession of this upper portion of the walls in consequence of glacial sapping or scour at their base could only have been by a process of shedding rock fragments upon the *surface* of the glacier. These fragments would accumulate at the terminal moraine; but the volume of the two terminal moraines together does not exceed 2,100,000 cubic yards. If we distribute this over the upper 1,200 feet of both walls of the canyon for the distance of 14 miles from the Kern-Kaweah river to the main terminal moraine, it would make a layer 4 inches thick. If we consider that probably half of the moraine came from sources outside the canyon, the layer would be reduced to 2 inches. This estimate may be modified and corrected in a variety of ways, but it leaves a quantity for the glacial widening of the canyon which is negligible. The canyon, then, had practically the same width before its occupancy by ice that it has today." (Pages 349, 350.)

The perfectly straight canyon was occupied by a bolt of ice more than 20 miles in length, formed by the junction at the valley head of two strong glaciers, and joined along its course by six tributaries, each formed from several glaciers (see Lawson's plate 31). So far as the drainage area (volume), valley conformation (freedom of flow), and latitude (temperature) could favor erosion, the Upper Kern glacier should have had great potency.

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*J. C. Branner: "A Topographic feature of the hanging valleys of the Yosemite." Jour. Geol., vol. 11, pp. 547–553, 1893.

†A. J. Lawson: "The geomorphogeny of the upper Kern basin." Univ. of Calif. Pub., Bull. Dept. Geol., vol. 3, 1904, pp. 291–376.

An important fact to be noted in connection with the fact of slight glacial erosion in the Sierras is the existence of "hanging" valleys.

> ". . . The apex of these cones is generally several hundred feet above the canyon floor. These cones are the product of streams which enter the canyon far above its bottom and which, in many cases, flow in glaciated trenches. *These trenches are fine examples of hanging valleys.*" (Page 329; italics not in the original.)

Lawson divides the Upper Kern valley into two parts:

> "an upper part, in which the Kern has been engaged in vertical corrasion since the retreat of the ice, and a lower part in which it has been engaged in aggradation."

He thinks that the aggrading portion

> "represents an overdeepening of the canyon floor by glacial scour, a process which has been exemplified in many glacial troughs, such as in some of the lochs of Scotland and fiords of Norway. . . . Both the degraded and aggraded portions of the glaciated canyon are U-shaped in profile, but the most perfect U-shaped profile is in the former, and is true of the rocky floor and sides of the canyon. The U-shaped effect of the aggraded portion is largely due to the talus slopes at the base of the canyon walls. If the rocky bottom of the canyon beneath the meadow floor be also U-shaped, as is very probable, then the depth of the aggradational accumulation may not be more than a hundred feet." (Page 349.)

The only doubtful matter would seem to be that of the conjectural basin. The fact of less perfect U form of the aggrading section, implying less total erosion, taken in connection with the small volume of morainal debris, and specially the absence in the latter of clayey material or product of abrasion, throws serious doubt on the suggestion of an erosional basin beneath the meadows. However, it is not an important matter, as a basin of 100 feet, or even greater depth, is inconsequential in the valley stretch of perhaps 8 or 9 miles.

We find in the Sierras all the important features which have been appealed to for proving enormous ice erosion, particularly U-shaped canyons and hanging valleys; but the geological experts are practically unanimous that the Sierran valleys are preglacial, and at the most have only been more or less modified by glaciers. But now, if these topographic features can exist in the Sierras without great deepening of trunk valleys, then it seems illogical and unreasonable to require vast deepening in Norway or Alaska to account for the same features.

The only equivocal matter which we find in the Sierran study relates to the shallow rock-basins, but they can be explained without requiring any scouring of live rock; and in any case they are insufficient foundation for an assumption of thousands of feet of deepening.

Cascades.—A very recent paper by Willis[*] revives the interesting question of the origin of lake Chelan, favoring the suggestion[†] of ice erosion.

The problem of the Chelan basin is practically the same as that of other deep lakes, like the Swiss lakes, found in the tracks of former stream glaciers,[‡] and it is well to discuss it here at sufficient length. The descriptions following are from Willis' paper:

"Lake Chelan is a slender body of water, 65 miles long, whose southeastern end lies open to the sky between the grass-grown hills of the outer Columbia valley, while its northwestern lies in shadow between precipitous mountains in the heart of the Cascade range. . . . The canyon is that of the Stehekin-Chelan river, which rises in latitude 48° 30′ in glaciers of the Cascade range at altitudes of 5,000 to 8,000 feet. The headwaters descend very abruptly, 1,000 to 1,800 feet in the first mile below the glaciers, and combine in a U-shaped valley of gentler grade, the fall being 2,500 feet in 23 miles. This section is cut in rock bottom. For 12 miles farther down stream the valley is floored with boulders, coarse gravel, and sand, and the slope is but 20 feet to the mile, ending in the delta which the stream is building into lake Chelan.

"The gravel-filled section of the valley is no doubt deeply cut in the solid rock, since but a short distance beyond the front of the delta the lake is more than 500 feet deep. For a distance of 35 miles the depth varies from 1,000 to 1,400 feet, 1,419 being the maximum yet sounded. As the water surface is but 1,079 feet above sea, the bottom of the lake is for a short stretch 300 feet below sealevel, and an interesting question is raised as to how so deep a basin originated. Fifteen miles from its outlet the lake begins to shallow, and in its lower reach does not exceed 200 feet in depth." (Page 58.)

"Lake Chelan occupies a canyon in granite and gneissoid rocks. The waters are retained by a dam of drift, but discharge through the gorge of Chelan river into the Columbia, whose bed is not far from solid rock. According to the altitudes above sea of rock in place in the Columbia, several miles below the junction, that of the lowest rock sill over which the waters of lake Chelan can have escaped is about 700 feet. . . . The maximum sounding was 1,419 feet—*i. e.*, to 340 feet below sealevel, or 1,040 feet below the rock rim of the basin." (Page 81.)

"Effects of glacial erosion are obvious throughout the Chelan-Stehekin system. They may be traced from the moraines of existing glaciers, in the cirques about the headwaters, down the grooved and rounded canyon walls, into the waters of lake Chelan, and out to the terminal moraine near the Columbia, in all a distance of 70 miles. Three miles above the terminus of the ancient glacier its thickness was 1,000 feet, and its surface stood about this amount above the present level of lake Chelan. Thirty miles above its lower end, that is, near Safety Harbor creek, the thickness of the ice was 4,500 feet, and toward the head of the lake it probably exceeded 5,000 feet." (Page 82.)

" . . . The walls of the canyon are sloping, not precipitous. . . . The

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[*] Bailey Willis: Physiography and deformation of the Wenatchee-Chelan district, Cascade range. U. S. Geol. Survey, Profes. Paper No. 19, 1903, pp. 41-97.

[†] Henry Gannett: Lake Chelan. Nat. Geog. Mag., vol. ix, pp. 417-428, 1898.

[‡] The New York or Finger lakes are an entirely different problem, as their valleys were never occupied by stream glaciers, but only by lobes of the continental glacier in valleys sloping toward the ice (see discussion, pages 55-73).

> maximum inclination is usually near the water surface, and for a hundred feet or so may locally approach 60 degrees. Generally it is less than 40 degrees. And from this steepest facet the profiles rise in a curve which is convex upward, and pass into the nearly level spurs of the adjacent ranges." (Page 59.)

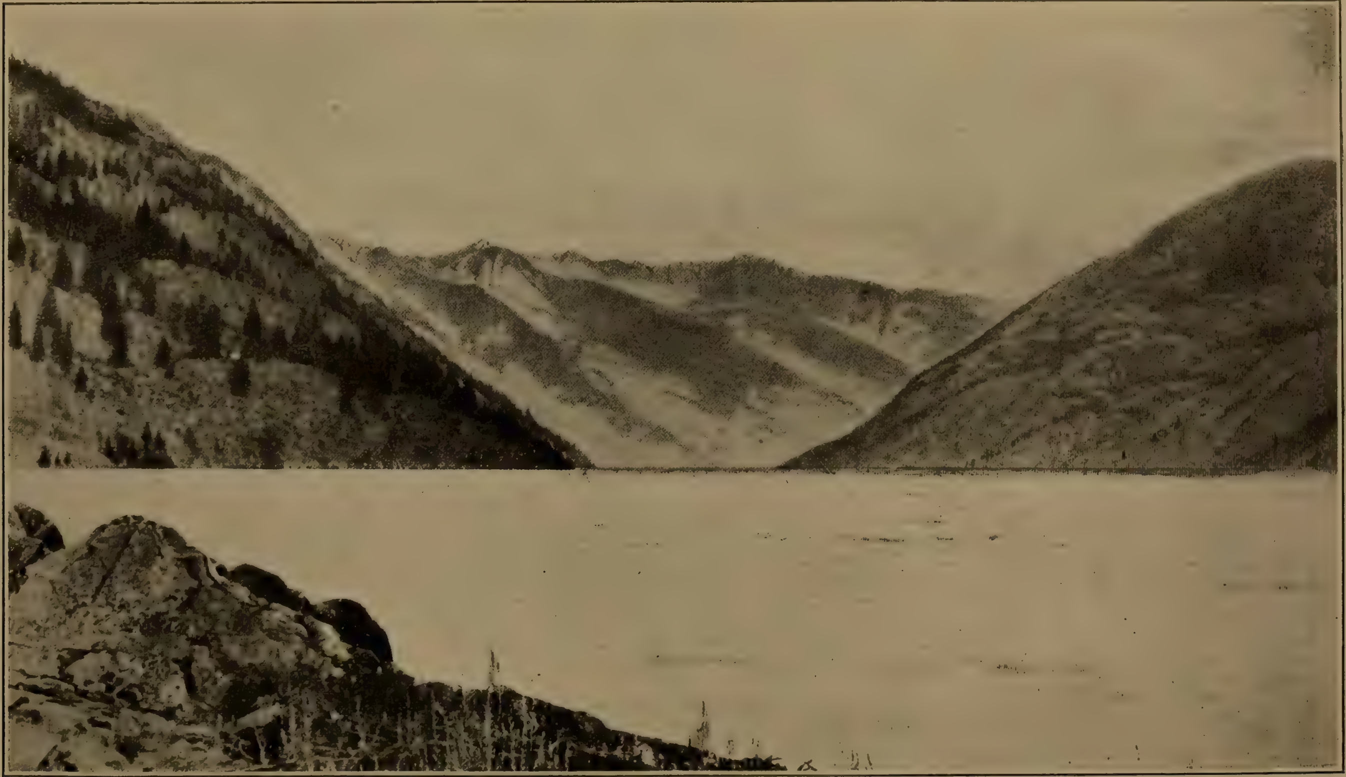
Questioning the amount of glaciation in the general region and on other valleys, the author admits that the valleys are preglacial and have only been modified, and that the Chelan valley is peculiar. Following are the words:

> "In the glaciated region of the higher Cascades, the canyons are developed on a grand scale. Russell has rightly described them as extending with channels at railroad grades into the very heart of the mountain mass, and they are from 1,000 to 3,000 feet in depth. They have been widened and deepened by ice-work, to what degree is not to be determined, but apparently in some instances greatly. Nevertheless, when all reasonable allowance has been made for glaciation, the canyons which may be ascribed to corrasion during the Twisp stage (preglacial) were of great depth. They were relatively narrower than they now are, and their topographic development had the character of advanced youth." (Page 81.)
>
> "A further test of this conclusion (ice deepening) may be applied by contrasting it with other valleys in the same region, many of which have been occupied by glaciers, and none of which exhibit similar peculiarities." (Page 83.)

Plate 16, reproduced from Willis' paper, shows the cross-profile and the proportions of the valley at "The Narrows," the narrowest part of the gorge, which is also the deepest part of the lake. This shows that the valley is decidedly V-shaped in the deep section, and the profile of the walls convex when the submerged section is included. These are the opposite of glacial characters. The gorge here shows no lateral erosion, although glacial widening is claimed for other valleys of the region. It is also admitted that no other valleys of the region exhibit the peculiar features of the Chelan gorge, the suggested explanation being the greater volume of the Chelan glacier.

From the published facts, mostly quoted above, we are unable to find any evidence whatever of ice erosion in the Chelan gorge. All our knowledge of glacier work opposes the idea. Where are the concave profiles and U shape, recognized as special characters of valley erosion by glaciers, and where is the enormous mass of clayey moraine which should have been produced by such vast abrasion? No description is given of the drift. It is inconceivable that a glacier should deepen a narrow gorge 1,000 feet and yet produce no perceptible cutting of the valley walls. The walls at the narrows were the obstruction which would have been cut away.

The fact of the depth of the gorge being inversely proportioned to the width has been suggestively explained as an effect of increased velocity in the narrow section, citing the behavior of rivers. The comparison



NARROWS OF LAKE CHELAN

After Willis

seems faulty. The river cuts down faster in its narrowed section because it saws only at the bottom (but even then it does not excavate deep basins), while the glacier cuts faster at the sides, and is prohibited from rapid bottom cutting by every known factor and principle of glacier mechanics.

Ice erosion has been assumed as the cause of deep lake-basins which lie in beds of former glaciers probably because it is the only near-by agent on which suspicion can fall. It has left evidences of its presence at the locality of the deed; but the circumstantial evidence is here misleading. We probably have in these lakes a much larger and more difficult problem than has been supposed. The idea of glacial erosion must certainly be abandoned, and the problem needs to be investigated along other lines. Following are a few suggestive facts which have a bearing on the subject.

If the deep Chelan basin were due to ice erosion, it would seem as if lakes of similar character should be common in glaciated mountains. There is apparently no good reason for attributing any exceptional character or power to the Chelan glacier. But lakes of the Chelan type are strikingly wanting in glaciated areas. No lakes occur, so far as atlases show, in the Caucasus, Pyrenees, Urals, or Carpathians, all of which mountains held strong glaciers, and only a few are shown in the Himalaya, mostly in the western districts, but no description of their character is available. The Swiss and Italian lakes are most surely not produced by ice erosion; but the deeper ones, like Zug, 650 feet deep; Geneva, 1,100 feet deep, and Maggiore, 2,600 feet in depth (the bottom 1,900 feet below ocean), seem to belong in the Chelan category. The Dead sea, with its surface 1,300 feet below sealevel, or Assat, east of Abyssinia and far below sea, are types of basins which require explanation as truly as Chelan, but no one has yet ventured to suggest ice erosion. If orographic or subterranean movements or local subsidence can reasonably be invoked for these basins, possibly even so narrow a basin as Chelan may have similar origin.

The comparative absence of lakes in non-glacial regions is often overemphasized. An inspection of a good atlas will show numerous lakes scattered the whole length of the American cordillera from Colorado to Chile; also in other non-glaciated mountain districts. It is probable that many of these intermontane lakes can be explained only by earth movements. An exhaustive investigation of the subject will possibly find that Chelan, Maggiore, and Dead sea belong in the same type.

Alaska.—There have been references to the glacial origin of valleys and fiords in Alaska, and statements to that effect; but, so far as the writer has found, no argument has been made nor proofs offered, except the general assumption from fiords and hanging valleys. The very important work of Russell over a large area in the northern lands, specially on the Malaspina and the Mount Saint Elias group, brings out no facts favoring erosion.

The most studied glacier in Alaska is the Muir, which furnishes only indisputable evidence of its failure as an erosive agent. The Muir is now uncovering, or receding from, a thick deposit of gravel and forest ground which it had overridden during its latest advance, and did not remove. The fact is recognized by all students of the region, and the abundant literature* makes the extended description here unnecessary.

Cushing writes as follows:

> "A glacier of great thickness (over 2,000 feet) has advanced over these gravels, and done so for considerable time. . . . The influence of the ice upon it must have been more protective than anything else. . . . These deposits have for their floor an old land surface, with tree stumps still standing in the soil in which they grew, . . ." (Page 220.) "At Muir glacier, in just the position where the greatest erosion would naturally be expected, soft gravels have been undisturbed by the ice." (Page 230.)

In discussing this behavior of Muir glacier, Russell says:

> "That glaciers of great thickness may overrun unconsolidated gravels, without disturbing them, is no longer open to question." (Paper noted above, page 194.)

He then refers to such deposits beneath the Malaspina glacier, and to uncovered gravels near Mono lake, California.

More than other writers, Professor Cushing has noted the erosional phenomena of the Muir Glacier region, and his observations are interesting and important, and negative in their force.

> "On all the mountain slopes which Muir glacier has overrun, a tendency toward the production of a surface consisting of small, shallow valleys separated by low ridges is seen, both trending in the direction in which the ice has moved. . . . The production of such surfaces in this region depends on the presence and distribution of the fissure planes. Weathering takes place along these planes to varying depths, resulting in the loosening of V-shaped blocks of varying sizes. After such decay has been in progress for a considerable length of time, a glacier riding over the ridge and removing loosened material will tend to leave a surface composed of ridge-like projections with shallow depressions between.
>
> "*Lakes.*—On the tops of the low mountains bordering Muir glacier, over which

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*S. P. Baldwin: "Recent changes in the Muir glacier." Am. Geol., vol. xi, 1893, pp. 366-375.

H. P. Cushing: "Notes on the Muir glacier region, Alaska, and its geology." Am. Geol., vol. viii, 1891, pp. 207-230.

H. F. Reid: "Glacier bay and its glaciers." Sixteenth Ann. Rep. U. S. Geol. Survey, pt. i, 1896, pp. 415-461.

I. C. Russell: "Origin of the gravel deposits beneath Muir glacier, Alaska." Am. Geol., vol. ix, 1892, pp. 190-197.

G. F. Wright: "Ice age in North America," 1902, pp. 36-66.

the ice has swept, diminutive lakes occur. . . . They occupy small depressions or basins on the tops of these ridges. . . . They are all very small, only a few yards in diameter and with no great depth. Some of them clearly occupy rock basins. . . . The conclusion can not be avoided that these hollows were the work of ice. In most cases the method of their formation seems clear." . . . (Page 227.) "All these basins which I saw lie in small valleys on the mountain tops, whose presence seemed to depend on the fissure systems and on the varying depths to which loosening of the blocks had taken place. They lie at the foot of slopes, down which the ice moved, impinging with unusual force at its base, where the greatest amount of polishing and striating has taken place." (Page 230.)

"The rough edges have uniformly been somewhat smoothed, but the character of the surfaces seem to me to clearly show that the valleys and the basins have been formed by the removal of loosened blocks, leaving a rough, jagged surface, whose edges have been smoothed and polished." (Page 227.)

"*Old surface features not obliterated.*—On the mountains in Muir Glacier basin from which the ice has recently retreated, surface features are occasionally observable which seem incompatible with the theory that glaciers vigorously erode hard rock. . . . That the glacier has done little more than to remove the loosened rock and polish the resulting surface is shown in a vast number of localities here by the character of that surface." (Pages 228, 229.)

The existence of numerous islands in Muir inlet and Glacier bay is conclusive proof that this fiord was not made by glacial erosion (see Cushing's paper, page 227). His comments concerning the wash from the glacier confirm the statement made on page 21 of this paper to the effect that such estimates of the abrading power of the ice were valueless. He says:

"Estimates of the amount of material brought down by the glacier are difficult to obtain owing to the fact that the material is all carried into the sea; that the number of subglacial streams is not known; and that there is no evidence that those which issue from the ice directly into the water carry as much sediment as those which issue from the corners and flow through the gravels. I could find no evidence inconsistent with the supposition that the debris falling on the surface of the ice yearly, together with the previously disintegrated material which the ice has removed and is removing, is amply sufficient to account for all the detritus deposited at the front of the glacier. The amount of material in sight on the surface of the glacier is enormous." (Page 229.)

Doctor Gilbert's recent work on Alaskan glaciers* regards hanging valleys as proof of the glacial origin of the Alaskan fiords. The competency of Pleistocene glaciers to excavate one or two thousand feet in crystalline rock is assumed. If such explanation were correct, then it should harmonize with all other geologic facts of the region; but it is apparent that the phenomena are not in accord under this hypothesis, for with his characteristic fairness the author mentions inconsistencies and difficulties, and other questions might be raised. A few of these points will be here mentioned.

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*G. K. Gilbert: "Harriman Alaska Expedition, III, Glaciers," 1904.

Gilbert agrees with Willis that the fiords of Puget Sound district are chiefly river work.

> "The system of troughs it (the ice sheet) left behind are regarded as pre-existent stream valleys, only moderately scoured and straightened by the ice which overran and occupied them." (Page 135.)
>
> ". . . Regarded as stream valleys, the channels tell of a preglacial baselevel at least 500 feet, and probably 1,000 feet or more, below the present sea surface." (Page 136.)

The question would naturally be asked why Alaska should not have stood as high above ocean during Tertiary time as the district immediately contiguous and possessing the same physiographic characters, or what the rivers of Alaska were doing while those of Washington were cutting the valleys that are now fiords? The only argument which Doctor Gilbert makes against such land elevation as would permit the stream origin of the valleys now drowned is the following:

> ". . . Under present climatic conditions, such a change would carry a very large area above snow-line, and would so promote the alimentation of glaciers as to flood the whole district with ice and abolish stream erosion. Stream erosion therefore could not have been carried, by lowering of baselevel, to the lowest parts of the channel system without the aid of important climatic variation. Without doubting the possibility of wide range in independent climatic factors, it seems easier to assume that the lowering of baselevel was comparatively moderate, and that a considerable part of the down-cutting of the channels was accomplished by Pleistocene glaciers." (Page 136.)

The above argument seems to ignore the generally accepted fact of warm climate over arctic lands during the early and middle Tertiary, as shown by paleontologic evidence. Would it not seem easier to accept the evidence of warm Tertiary climate over northern lands and the stream origin of the Alaskan as well as the Washington fiord valleys, which gives a harmony of facts, than to assume that the Pleistocene glaciers could abrade the bottoms of their valleys 2,000 feet in crystalline rocks?

If Alaska had been during the Tertiary 1,000 to 2,000 feet lower than now, so that the fiords could not be the product of river work, there ought to be found conspicuous and indisputable remnants of an uplifted coastal plain, or at least lines of wave-work.

The difficulty of accounting by ice erosion for the plexus or anastomosing system of deep valleys which characterize the Alaskan and Washington coast, or for even seriously deepening them, is recognized but not discussed further than to offer a suggestion of differences in rock structure.

> "When it is considered that these fiords, being parallel to the coast, run athwart the general movement of the ice from land to sea, the fact that their depth is comparable with that of troughs lying in the direction of general movement is certainly remarkable." (Page 147.)

The absence of moraines or masses of drift over wide districts is noted as follows:

> "In the narrower parts of the inside passages we saw no accumulation of glacial drift." (Page 161.) "The glacial deposits we encountered are of trifling magnitude collectively in comparison with the glacial erosion, of which we saw evidence, and it was therefore inferred that the principal regions of deposition lay outside the field of our observation, . . . and that its outer margin was beyond the present line of coasts." (Page 162.)

If the Alaskan glaciers could abrade their valleys during the Pleistocene to enormous depths in the crystallines, then the erosional work was so rapid and effective that it could not have stopped suddenly, but conspicuous recessional moraines should be left in even the higher valleys. However, if the ice first cleared the stream valleys of weathered materials and subsequently simply slowly abraded the smoothed and firm rocks, as glaciers do today, then there should be no massive moraines in the higher valleys, and the facts are harmonious.

Speaking of the "inequality of glacial erosion," the author frankly says:

> "The great work which it has seemed reasonable to ascribe to ice in the deepening and widening of fiords and other troughs stands in striking contrast to the feebleness of ice erosion in other places, which permitted, for example, the preservation of the low peneplains of Annette island and the vicinity of Sitka. In the one case the depth of the erosion is measured by hundreds of feet; in the other by tens." (Page 160.)

The explanation then given of the supposed contradiction seems involved and inconclusive; but harmony would be secured, not merely in respect to this difficulty, but with other difficulties, by abandoning the idea of enormous ice-cutting anywhere in Alaska.

An anomalous irregularity of supposedly glaciated surfaces is explained by "plucking" (page 206); but this appeal to plucking to explain rough surfaces which are assumed to have been deeply eroded seems inconsistent with the following:

> "The work of rock sculpture accomplished by the middle and lower parts of a glacier is performed chiefly by the processes of abrasion and plucking. . . . If the plucked blocks have originally stood as projections they may be broken away, even if quite firm and flawless; otherwise it is probable that they can be removed only if originally separated by joints or other structural partings."

> ". . . The prominences are therefore abraded more rapidly than the adjacent hollows, and the profile is thus reduced to simple forms." (Page 203.)
>
> "Another factor on which rate of abrasion depends is pressure; the abrasion is more rapid as the pressure of the glacier against the bed-rock is greater. . . . Thus in a second way there is a tendency to reduce the profile of the bed to simple forms." (Pages 203–204.)

If plucking did occur in the beds of glaciers the scars should be found there; but plucking and abrasion are mutually opposing factors and can not long coexist. After abrasion has done its first work under the pressure of thick ice, how is it conceivable for plucking to occur in live rock? (See discussion, page 20.) Plucking can be an effective process only in superficial removal of loosened rocks. It is good evidence of lack of deep erosion.

Mention of the islets in the fiords is only made in saying that in number they are "uncounted," but the existence of numerous islets in the fiords is not consistent with the origin or the great deepening of the latter by glaciers.

The body of facts relating to Alaskan geology seem to be thrown into confusion by the hypothesis of ice erosion so intense as to deepen valleys 1,000 to 2,000 feet; but, under the view that the fiords are drowned stream valleys of the Tertiary uplift, modified by ice occupation in the Pleistocene, and with only proportionate glaciation over the general and intervalley areas, the phenomena will be harmonious. But the question may be asked, "What about the 'hanging' valleys?" The reply is that they can probably be satisfactorily explained when the effort is made in an inductive way. They exist in mountain regions where the idea of deep ice-cutting will not hold and even in regions which are unglaciated.* Discordant drainage features have been found about the Finger lakes, and the latter are positively not due to ice erosion.

The most striking discordance of valleys which has so far been shown occur in young mountains of crystalline rocks. Their relation to glaciation is probably only incidental, except that they may have been made more conspicuous by such moderate widening of valleys and steepening and smoothing of the valley walls as the ice has possibly done.

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*Since this paper was written Professor I. C. Russell, in reviewing Doctor Gilbert's book, in Science, vol. xix, May 20, 1904, page 785, questions the glacial origin of hanging valleys, and writes as follows:

"Again, in well glaciated mountains, like the Cascades and Sierra Nevada, the great differences in level between a main valley and its tributary hanging valleys, amounting in some instances to 1,500 or 2,000 feet, and this where the main valley is short and has but a comparatively small gathering ground for snow, must needs make the conservative glacialist pause before accepting the conclusion that such discrepancies are solely due to differential ice erosion. Other considerations in this connection might be mentioned, such as the fact that a deep glaciated valley with hanging valleys along its sides not infrequently heads against a cliff, and its direct continuation above the cliff also has the characteristics of a hanging valley. Then, too, hanging valleys may be claimed to occur on the sides of steep mountains and on slopes overlooking the sea, where no evidence of a controlling ice body at a lower level is obtainable."

PHILOSOPHICAL CONCLUSION

Even a small amount of ice wear may be conspicuous, while the actual amount of erosion will commonly be indeterminate. However, there are decided limitations to the possible degrees of erosion, and ignorance of the limit gives no warrant for excessive claims, even if it does give the opportunity. When along with the quantitative uncertainty of the amount of ice-work there is combined qualitative doubt in the diagnosis or interpretation of physiographic features, then the matter becomes chiefly a question of mental attitude and personal judgment.

The claims for extreme glacial erosion have been almost entirely founded on physiographic characters—deep lake basins, fiords, and hanging valleys. This was true of Ramsay and his followers in England, of Helland and his school in Norway, and of the group of eminent physiographers in America. The assumption is made, without any attempt at proof except the physiographic argument, that Pleistocene glaciers could abrade thousands of feet in granitic rocks. The illogical argument may be briefly stated as follows: Hanging valleys are common in glaciated regions; they are not thought to be a normal product of stream work; they may be explained by glacial deepening of the trunk valleys; therefore the trunk valleys have been ice-deepened. But all the geologic evidence is to the effect that it was impossible in the time available for the glaciers to cut deep valleys. The advocates of ice erosion have never presented any proof from living or extinct glaciers that ice has made or is making or could possibly make a deep valley in hard, unweathered rock. The position is taken behind a bulwark of analogy and assumption.

The burden of proof is properly on the advocates of unlimited ice erosion; but it would seem wiser to essay the task of explaining anomalous topography by the operation of ordinary and competent agencies. It is far more probable that some physiographic element has been overlooked, or that knowledge is deficient, or interpretation in error, than that Norwegian and Alaskan glaciers did a kind and amount of work which glaciers in general have not done, are not doing, and apparently can not do.

We do not yet know the erosional conditions and effects resulting from rapid uplift of high mountains with cores of crystalline rocks of heterogeneous structure and under the probably warm and humid climate of the pre-Pleistocene. "Hung up" valleys will probably be found a normal product of atmospheric and stream work under some conditions of vigorous drainage, with or without rock displacement.*

PART II. ICE-SHEET EROSION IN NEW YORK

GENERAL PRINCIPLES

The previous writing (Part I) has treated specially of the work of alpine or stream glaciers. These did not exist in New York—at least in the part of the state which we will study. The phenomena here represent the work of a "continental" ice body, and afford another critical test of the doctrine of deep ice erosion—particularly as they include the "Finger" Lake region. It needs to be clearly stated that any erosion of the basins of the New York lakes was not by alpine glaciers, but by mere lobations of the great Ontarian ice mass, as will be shown later.

The work of continental ice sheets has not been so much in question as that of stream glaciers; but the distinction often made between the erosive effects of alpine and continental glaciers is not well founded. Erosion is dependent on the combination of the factors of velocity, pressure, abrasive tools, and clearance, and any difference in the erosion by stream glaciers or continental glaciers is a matter of the intensity and reaction of these factors, the valid distinction being simply the variation of these factors, the same as between two alpine glaciers. However, it may be granted that the action of continental glaciers may involve conditions which can not be determined by study of stream glaciers. The more general effect of continenal glaciers has been regarded as that of leveling, by planing of elevations and rubbing of drift into the depression. Yet, while the extravagant claims for the erosive effects of the "Polar ice-cap" made by the early glacialists have given place to more moderate views, the idea is still prevalent that the ice bodies had great excavating power. References are still made to "deepening of the Great Lake basins" and to the "glacial origin of the Finger lakes."

The general failure of continental glaciers to effectively erode even soft deposits under their marginal portions is shown by the vertical succession of glacial and interglacial beds left over wide areas of slight relief, as in the Mississippi area; but a theoretical distinction has been drawn between peripheral zones of deposition and the central areas of erosion. Naturally the evidences of removal of material and abrasion of surfaces are pronounced in the centers of glaciation, and many observations are recorded which indicate superficial erosion, but not deep cutting of firm rock.

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* For an example of such features by faulting see "The hanging valleys of Georgetown, Colorado," by W. O. Crosby, Tech. Quart., vol. xvi, March, 1903, pp. 41-50.

The Scandinavian geologists have claimed immense erosion of their highlands in order to account for the great volume of drift spread over the German lowlands and other areas marginal to the ice body. The probable exaggeration of the drift volume is accompanied by an underestimate of the amount of rotted material in the crystalline regions, due to millions of years of preglacial decay. Such arguments are attractive in affording scope for the imagination, but they deal with uncertain elements and are very indefinite and inconclusive.

The best illustration of the erosional effects of a great continental glacier is found in the broad area of Canada, and the facts are clearly stated in the following extract from a recent letter by Professor A. P. Coleman:

> "It seems to me probable that a vast ice sheet, like the great Labradorian glacier, would erode comparatively little near its center, much more powerfully midway from the central area toward the margin, and not at all at the margin. Your carefully studied New York region is too near the edge to show much erosion. The bottom of the sheet was clogged with coarse and fine debris by the time it reached you, and was incompetent to do much erosion. The same is true north of lake Ontario, as at Scarboro Heights, where the advancing Wisconsin ice pushed up over the stratified interglacial delta deposits of the Laurentian river with little effect, even over the upper stratified sand. . . .
>
> "In the Sudbury district, however, much more scouring has been done, and very little moraine stuff and no preglacial weathered rock is to be found. All has been pared down to the fresh rock. The surface is, however, probably not very greatly different in relief from the preglacial one, since the harder bosses and ridges are still strongly marked hills, well rounded toward the northeast, rougher toward the southwest. Many of them have the moutonnée form, especially the granite hills.
>
> "The great morainic deposits of southern Ontario consist mainly of very fresh materials, even decomposable basic rocks, such as olivine diabases, coming out of the boulder clay in perfect freshness. Our boulder clay and morainic stuff do not show any signs of weathering or oxidation of the geest. Perhaps all the surface material was swept farther south across the lake.
>
> "Though the amount of plucking and of erosion of live rock in this region, where I imagine ice erosion to have been most effective, is important, I do not estimate the average amount of cutting down of the surface as very great, probably considerably under 100 feet. We have numerous rock-basin lakes, but so far as I have seen all are small and not very deep."

The territory of New England and New York lies in the intermediate and debatable ground between central wear and marginal deposition. The practical absence of interglacial deposits in New York may be due, theoretically, either to greater erosive power of the later ice or to continuity of the ice occupation.

The high topographic relief of eastern New York is regarded as unfavorable to glacial erosion, but the great depressions followed by the ice flow, the Hudson and the upper Saint Lawrence valleys, should display maximum effects.* A favorable area for ice erosion is the Ontario basin, and specially the plain and plateau border south of the lake, partly because of the relation of the ice movement to the land surface and partly because the rocks are unusually soft and non-resistant. The Niagara plain was continuously overridden by the great Ontarian lobe of the Labradorian (Laurentian) ice body, while the Finger Lakes region received the full force of the southward flow of the spreading Ontarian mass. Western central New York thus offers a most excellent field for the study of glacial erosion, and it is a critical locality, since here more than for any other region in America the claim has been made for deep cutting by the ice. The writer has evidence that such claims are false, and the proofs will be given below in proper sequence.

Another distinction between the work of continental and alpine glaciers must be mentioned here, for it seems to have been assumed that the supposed cutting in the basins of the Finger lakes was done by what were practically stream glaciers.

To the degree that the margin of the ice-body was lobate, or had the flow concentrated along certain lines in the depressions of the land surface, the wear would approach that of stream glaciers; but there is an important theoretical distinction. The alpine glacier is supplied with rock rubbish and cutting tools by the weathering agencies at the valley head and sides. Like a river, the valley glacier is carrying a load of contributed detritus, which renews its cutting power along the margins. The ice mass which occupied the Ontario basin and the Finger Lake valleys had to do their work wholly by the slow abrasion process at the bottom. The short lobes or tongues, which during advance and retreat of the ice sheet occupied the valleys of the Finger lakes, had very little resemblance to alpine glaciers in either origin, form, or effect, for it must be understood that they were pushing uphill.

EFFECTS IN ADIRONDACK REGION; NORTHERN NEW YORK

In the Adirondacks we have a highland area comparable in some ways with Scotland. It was probably a center of local glaciation and was also overridden by the great ice body from the north. While all students of the area find striking evidence of ice action, no suggestion of deep ice-cut valleys or basins have been made. Personal inquiries of two geologists who are very familiar with the field have elicited neither facts nor opinions favoring deep localized erosion. Professor H. P. Cushing writes:

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* A recent paper, "Trent River system and the Saint Lawrence outlet," by A. W. G. Wilson, forming pages 211–242 of volume 15 of the Bulletin, furnishes conclusive evidence of slight erosive work of the Labradorian ice body north of lake Ontario and in the Saint Lawrence valley. The facts are presented on pages 221–224, with a summary on page 240, and are essentially the same class of evidence as given in the present writing for the south side of the Ontario basin.

"My impression is that the northern slopes of the region have been considerably smoothed by ice action in its uphill climb there. There are cirques in the high peak district, and possibly a number of rock-basin lakes. Some of the passes may have been shaped by ice action. The rocks are very hard, but they are also much jointed, so that plucking might well go on along valley sides. There has been a tremendous amount of rock material, much of it very fresh, moved about by the ice, but it is of course impossible to say whether any amount of it was actually quarried by the ice or not. The joints would facilitate it if such action does take place. Certainly all rock in any way weathered was removed by the ice. The whole surface is rochemoutonneéd, especially on the north, where nearly all rocks are absolutely fresh. Even the diabase dikes, which are of pre-Cambrian age, often show the olivines perfectly fresh, and this when they cut hard, resistant granitic gneisses, which are worn down to the same plane as the dikes. I am sure there is no evidence in northern New York that the ice has cut any valleys."

Professor C. H. Smyth, Jr., gives testimony to the same effect.

The most definite observation directed to this subject has been placed on record by Doctor Gilbert* and it is negative. This is the more significant, since it occurs in writing which favors the conception of ice erosion. After referring to the paper by Goodchild (see page 33) and expressing the opinion that the district of the Finger lakes "owes more to ice work than to antecedent water work," he writes as follows:

" . . . , and in northern New York, where the rocks are comparable in hardness with those of the Scottish district, the ice seems to have accomplished comparatively little. Sandstones and limestones are not there so disposed as to afford good comparative data; but in a tract of crystalline schists lying northeast of Carthage and nearly bare of drift, the sculpture features are very different from those depicted by Goodchild. The principal structure of the schist is vertical, and its trend makes wide angles with the direction of ice motion. The ridges, which are at most only a few score feet in height, conform in trend with the strike of the foliation, and have been but slightly remodeled by sculpture on lines of ice motion. The bosses of the moutonnée pattern are measured by yards or rods."

The locality near Carthage, lying on the northwest flank of the Adirondack massif, should have experienced vigorous erosion, since the ice crowded past and around the highland mass.

WORK OF THE ONTARIAN LOBE; WESTERN NEW YORK

On the Niagara escarpment.—Fortunately for our study we have in the Niagara escarpment, which extends east and west, parallel to the south shore of lake Ontario (see figure 2), a broad feature of preglacial topography which has preserved not only evidences of ice work, but very satisfactory proof of the slight amount of work. Doctor Gilbert has drawn attention to the erosion phenomena in the short but interesting paper already noticed and which we shall quote again.

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*G. K. Gilbert: "Glacial sculpture in western New York." Bull. Geol. Soc. Am., vol. 10, 1899, pp. 121-130.

Against the Niagara escarpment the Ontarian ice body impinged in the most effective way, both in momentum and direction. The movement was oblique to the cliff; and every mechanic learns that his cutting tool, chisel, rasp, or plane, does its best work when the cutting edge is held oblique to the line of motion. During all the life of the Laurentian ice in this locality, in all stages of its flow, the glacier struck this barrier at the very best advantage; and with what effect? The cutting by the ice has been just about sufficient to prove that it was comparatively very slight. More or less cutting might have left the record equivocal. Doctor Gilbert has described (figure 2) how the ice cut oblique notches in the crest of the escarpment. A horizontal profile along the brow of the scarp is serrate, with the serrations directed to the northeast, or against the ice-flow. Many, if not all, of these notches were originated by preglacial agents, and the ice has rubbed them, sometimes enlarging them and changing their axial direction. Doctor Gilbert says:

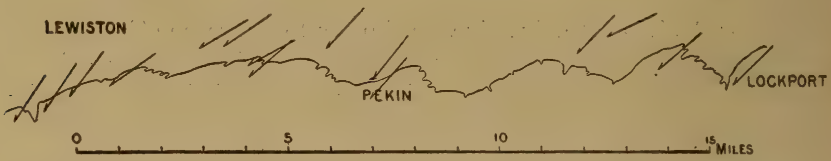

FIGURE 2.—*Contour on the Lockport Limestone at the Niagara Escarpment. After Gilbert.*

The escarpment faces north. Arrows show observed directions of glacial striæ.

> "All the more general features of the limestone belt thus seem to be preglacial."

After describing the limestone cliff in its form, relations, and erosion, he concludes as follows:

> "The configuration of the cliff seems to show that in the regions where the trend is southwest all minor salients have been pared away by the ice, and that where the trend is southeast minor irregularities of the face have been exaggerated and small reentrants drawn into furrows; but the principal salients and reentrants of the topography are preserved, and ice modification is limited to minor details of form.
>
> ". . . It would appear that the ice sheet concentrated its work, so far as the Niagara limestone is concerned, on the crest of the escarpment, and that even there its results were of secondary rather than primary importance. Probably the limestone at its escarpment lost on the average only 10 to 20 feet of thickness, and from the broad belt of outcrop the general loss may have been as small as 5 feet."

With the above descriptions and conclusions the writer is in accord, and the estimate of removal on an average of 10 to 20 feet of rock from

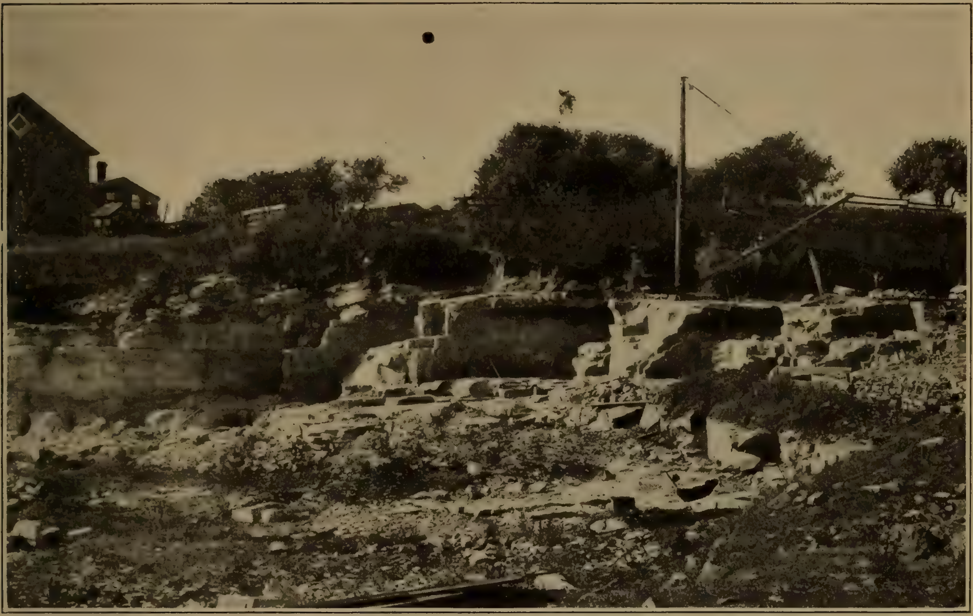

FIGURE 9.—LOCKPORT LIMESTONE, LOCKPORT, N. Y.

The limestone is at crest of Niagara escarpment. The derrick stands on perfectly preserved glaciation. At the left is seen higher and corroded beds

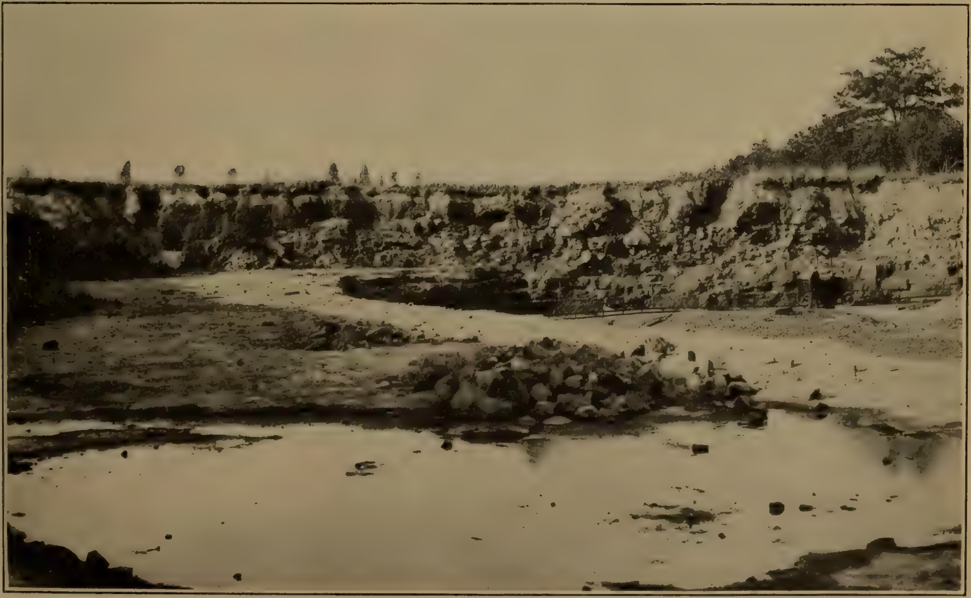

FIGURE 2.—LOCKPORT LIMESTONE NEAR ROCHESTER

Showing the deeply corroded dolomitic limestone

FAILURE OF ICE EROSION ON LOCKPORT LIMESTONE

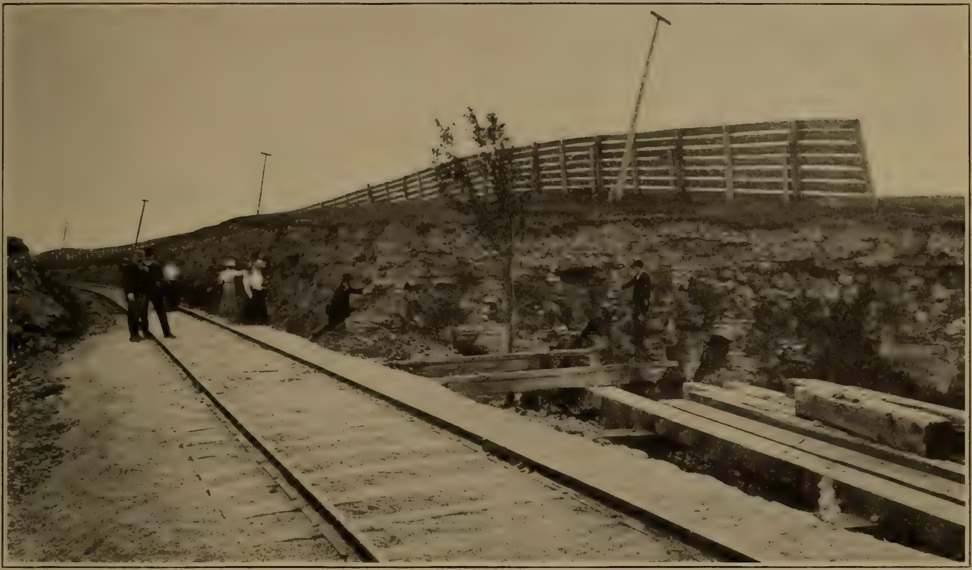

FIGURE 1.—AN OUTLIER CAPPED WITH ROTTED CORNIFEROUS LIMESTONE

This exposure is one-half mile north of Honeoye Falls, New York

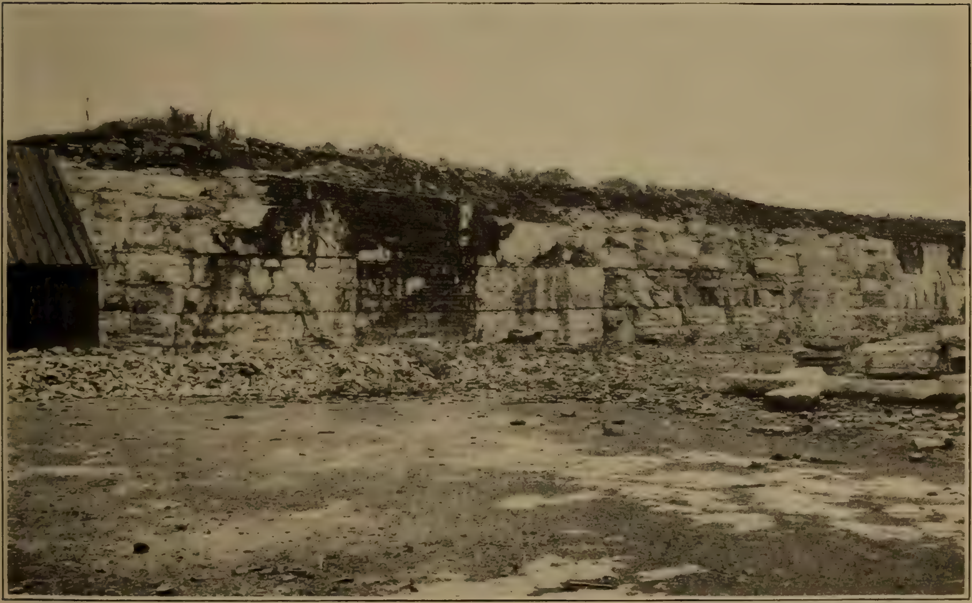

FIGURE 2.—WATERLIME CEMENT QUARRY, BUFFALO

Corroded beds of Corniferous limestone appear at top

FAILURE OF ICE EROSION ON CORNIFEROUS LIMESTONE

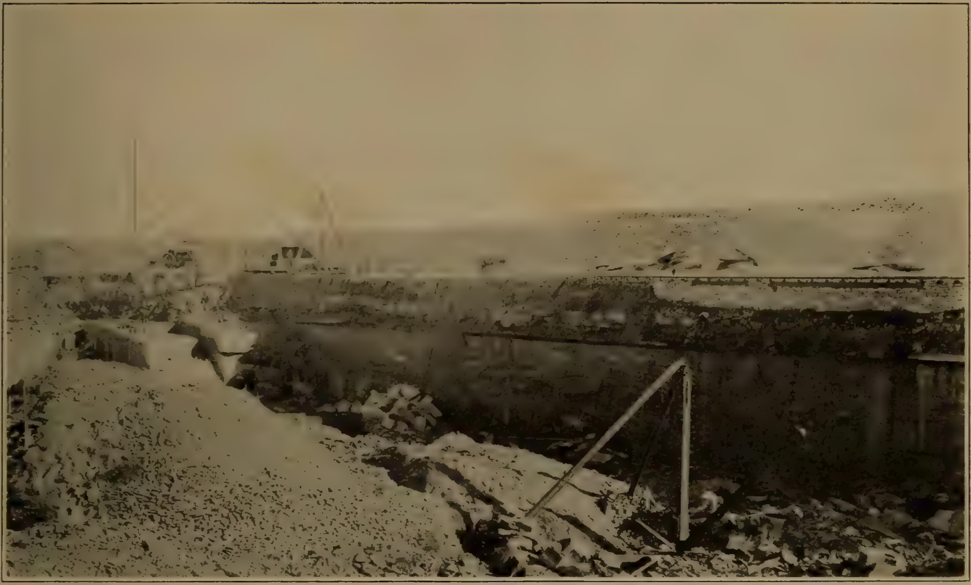

Figure 1.—Cornell quarry, Hulberton, New York

Corroded sandstone layers disturbed but not removed

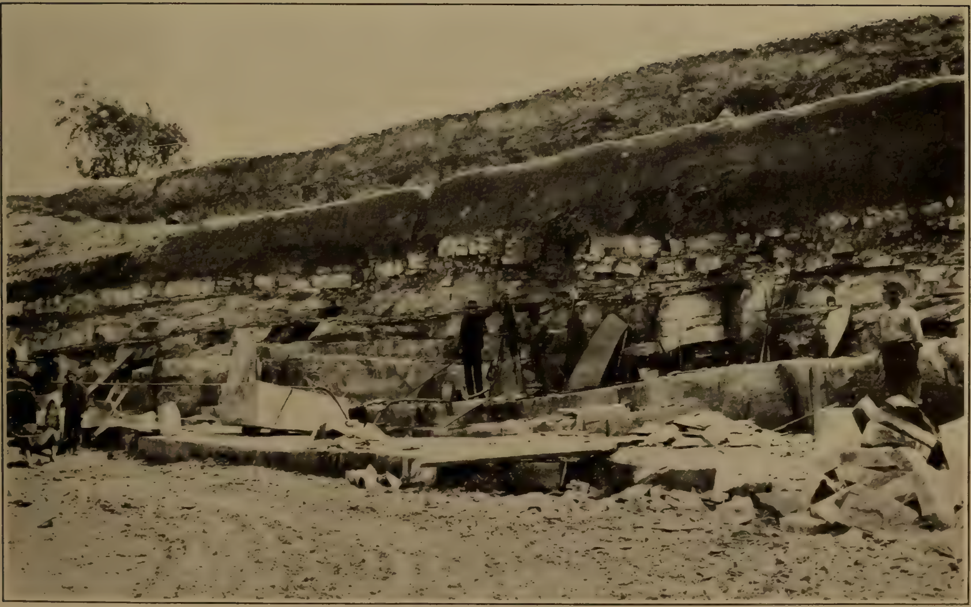

Figure 2.—Horan quarry, Medina, New York

Corroded sandstone layers undisturbed

FAILURE OF ICE EROSION ON MEDINA PLAIN

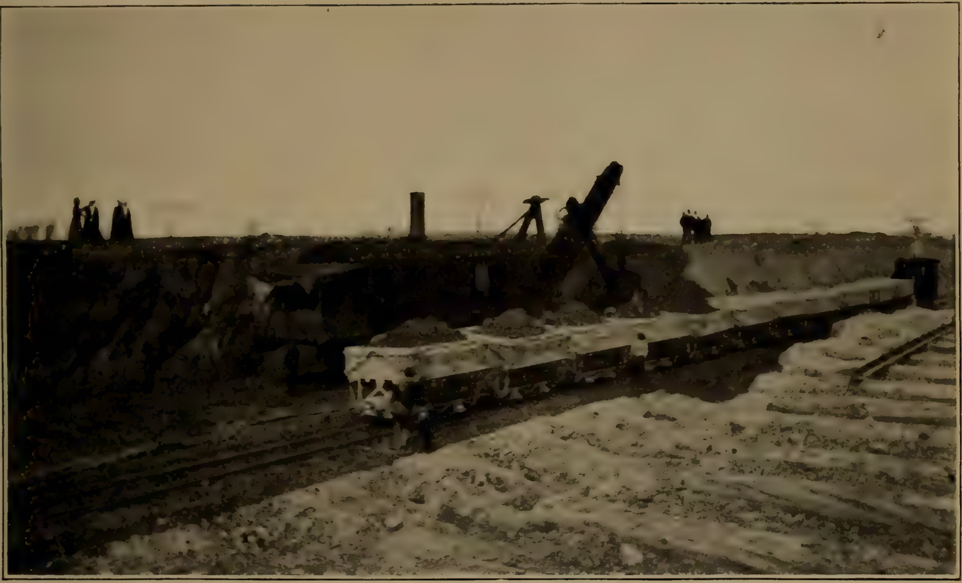

FIGURE 1.—ROTTED SALINA SHALES, EAST SYRACUSE, NEW YORK

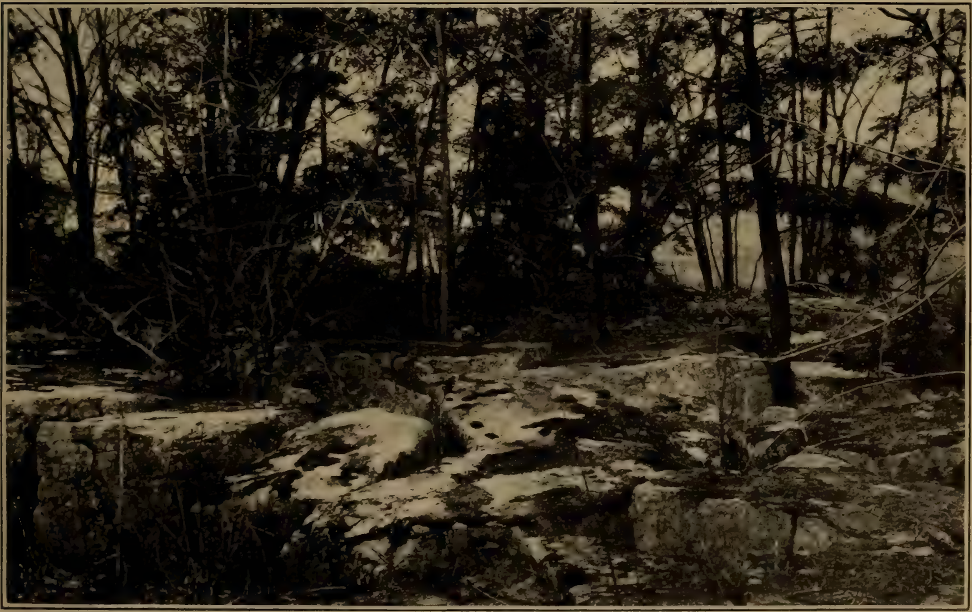

FIGURE 2.—"ROCK CITY" STRUCTURE IN ONEIDA GRIT

This locality is 6 miles northeast of Oneida

FAILURE OF ICE EROSION IN CENTRAL NEW YORK

the crest of the cliff is acceptable when we include in the removal the weathered rock. No distinction was drawn between the weathered and loose rock and the firm rock, and this is an important point in discussion of ice erosion. It is certain that along this cliff almost no erosion of the live, unchanged rock occurred. At many localities a weathered layer may be seen in position. Sometimes the ice removed all the weathered rock down to a hard bed, while the latter is merely scratched. Plate 17, figure 1, shows an example; the derrick stands on live, striated rock, while at the left is the remnant of an upper and rotted layer.

It is recognized, of course, that subterranean drainage and solution of the limestones probably extended to great depths; but the unequal resistance of the upper beds has frequently produced a very distinct plane between the severely weathered beds and an underlying bed that was slightly weathered (see plate 18, figure 2, plate 22, figure 2).

All through western and central New York the preglacially weathered rock may be found *in situ* in numerous and critical localities. It would seem to be conclusive evidence of lack of erosion, and will be referred to in discussing other localities. Plates 17–20, 22–23 are a few illustrations, selected from many photographs, which show the preglacial weathering on sandstone, shale, and limestone. Brief descriptions are appended to the cuts. Along the Niagara escarpment the weathered rock frequently appears where the drift is removed.

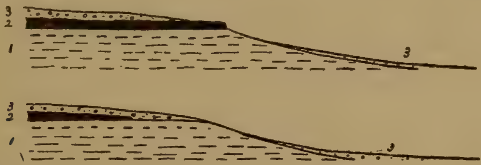

Figure 3.—*Typical Profiles of the Niagara Escarpment. After Gilbert.*

1. Shale. 2. Lockport limestone. 3. Drift.

After looking at the figures showing the serrated cliff the reader might ask if the peculiar profile might not be the final effect of deep erosion, by lowering, or backward ice-cutting, of the cliff. Doctor Gilbert presented conclusive topographic argument against this, and the above facts proving failure of erosion will place the matter beyond cavil.

The slight erosion of the limestone cliff, and the failure to remove even the crest of shale where this was unprotected by a limestone cap, as shown by Gilbert, pages 123 and 124 of his article, and illustrated in figure 3, is satisfactory proof that here, at least, the ice had little erosive power. And why not here? Every condition for vigorous erosion seems to have been fulfilled—an opposing cliff, not too high, composed of soft and jointed strata, trending at the very best angle for cutting, and the ice bottom freshly armed with Medina sands, gathered on the plain immediately northward, giving an abrasive much harder than the rock to be attacked.

Now, it is no sufficient answer to say that ice behaves capriciously, and we should expect local variation in its work. We should expect it to get in its work where it had the best chance. If it were the great engine of erosion which plowed out the Finger Lakes valleys it should have exhibited some of its power in this locality. It is both illogical and unfair to claim that the ice was locally weak in those places where there is proof that it did not cut, and then to assume that it cut hundreds or thousands of feet in other places where there is no evidence of any cutting, but only a topographic difficulty.

On the Medina plain.—In the article already quoted Doctor Gilbert suggests some fluting by ice erosion in the Medina shales which underlie the glacial and lacustrine deposits along the smooth belt bordering lake Ontario, which we will call the Niagara-Genesee prairie. The present writer regards the low swells, lying in the direction of the ice movement, or northeast by southwest, as essentially drumlins. Near the Genesee river, in Monroe county, they are typical New York drumlins. Westward in Orleans county they become lower and flatter, being only gentle swells, and they are finally almost imperceptible in Niagara county. Most of the western half of the prairie is perfectly flat to casual observation. No rock exposures have been found by the writer on any ridge, although Doctor Gilbert refers to such, but the rock is frequently seen in the hollows or troughs in the stream beds. Along the lake shore the waves of Ontario have dissected the plain, though not deeply, and the ridges and swells show only till.

The singular parallelism of the stream directions, chiefly northeastward, was certainly determined by the surface form of the superficial drift, even if the ridges might sometimes have a rock core. However, the point is not worth any extended or detailed discussion here, for the matter in question is quantitatively unimportant. Doctor Gilbert suggests a furrowing of the underlying shales of only 40 or 50 feet, which is very moderate if the geest be included, as it properly should be; but even much more erosion than this in weathered Medina shales would be poor basis for claims of enormous cutting in granitic rocks.

This paper by Doctor Gilbert is very significant in a negative way. It should be expected that in a paper discussing and favoring ice erosion he would present the best evidence possible. He admits the absence of erosion on the schists near Carthage. On the Niagara cliff he concludes that the erosion was inconsiderable. The most he finds is some removal of the Clinton along the escarpment and a furrowing of the soft Medina with "a general reduction of the surface to the extent of 40 or 50 feet, and the amount may have been considerably greater." When we consider that whatever removal is admitted must include the weathered and loosened material, it makes a poor showing for ice erosion.

Since Doctor Gilbert, with his long experience and wide observation in the field, with his special interest in glaciology, and with his commanding ability, can give the erosionists no better support from direct evidence than this, they certainly have a very weak case. The statement is again pertinent, that no good example of deep erosion has ever been proved.

EFFECTS IN THE FINGER LAKES REGION; CENTRAL NEW YORK

General description.—The topography of central New York has long been known as striking in relief, peculiar in form, and puzzling in origin. A series of deep valleys, with a north and south direction and a northward pitch, holds a series of lakes having a digitate arrangement, of which Seneca and Cayuga are the central and larger members (see map, plate 21). These valleys are excavated in uppermost Silurian and Devonian strata which are practically horizontal, but with a low southerly dip. Several of the valleys do not hold lakes. The valley walls are decidedly convex, and sometimes conspicuously smooth in general view, and southward toward the valley head are generally steep.

The intervalley ridges are broad, rounded remnants of the north-facing slope of a dissected plateau (the Allegany cuesta), with an altitude at the north ends of about 500 to 800 feet above sealevel. Southward the ridges rise in 20 to 40 miles to about 2,000 feet, the higher strata being Portage-Chemung sandstones.

The two larger valleys, holding Seneca and Cayuga lakes, have received most attention from writers and have been specially quoted as examples of deep ice erosion. But any sound theory for the genesis and history of these two valleys must also explain all the parallel valleys, from the Genesee on the west to Chittenango on the east; they all belong in one category and have practically the same history.

Another remarkable set of large valleys, which have not received much attention, are discordant in direction, and probably in altitude, with the north and south valleys. They have a general direction northeast and southwest, and intersect the north-south valleys. The most northerly example extends from the present head of the Onondaga valley, at Tully, northeast past Apulia and Fabius to the limestone valley near Delphi. Another one extends from the Cayuga valley at Ithaca northeast past Cortland and Truxton to the limestone valley at De Ruyter. Still another intersects, near their heads, the valleys of Canaseraga, Hemlock, Honeoye, and Canandaigua. These great transverse valleys have their bottoms obscured by drift, but the writer thinks that their rock bottoms are higher than those of the north-south valleys, and that they represent the work of an earlier drainage.

The erosional history of the region from the time it was lifted out of the Devonian or Subcarboniferous sea, down to the time of the Pleistocene ice invasion, must have been eventful as well as long, and have involved great changes in attitude. We may believe that the primitive, consequent drainage from the Adirondack-Laurentian oldland was south and southwest across the new coastal plain to the Mississippian sea. The broad and high transverse valleys mentioned above may possibly be an inheritance from that earliest drainage. Eventually the broad Ontarian depression was produced as a subsequent valley along the outcrop and strike of the very thick and non-resistant strata of the Lower and Upper Silurian, and along with the production of this great east and west trunk valley came the development of the (obsequent) drainage down the inface or north slope of the plateau (the Allegany cuesta) which has left, as the finality of all the erosion, the north and south valleys that hold the Finger lakes.

The above is merely a suggestion of the events in the long and obscure history; but it seems probable that during the long exposure of the region to erosive agencies, during the later Paleozoic, Mesozoic, and Cenozoic eras, many changes must have occurred and the normal development of the drainage have been modified by up and down land movements, with more or less tilting of the area.*

The topographic forms and the valley relations have made this region an enigma to the physiographers. If all the rock topography as left by preglacial drainage were exposed to view the expert translators of physiographic records might tell us most of the old history; but, unfortunately (or fortunately), the ice-sheet transgressed the entire region and rubbed its load of drift into the valleys in very irregular manner, and has badly obscured the preglacial topography. The precise relationship of the valleys can not be known until borings determine the rock floors.

The topography is anomalous, puzzling, and fascinating, and as it can not be immediately explained by supposed laws of stream work some students invoke the aid of ice and assume that glacial erosion is responsible for the unusual features.

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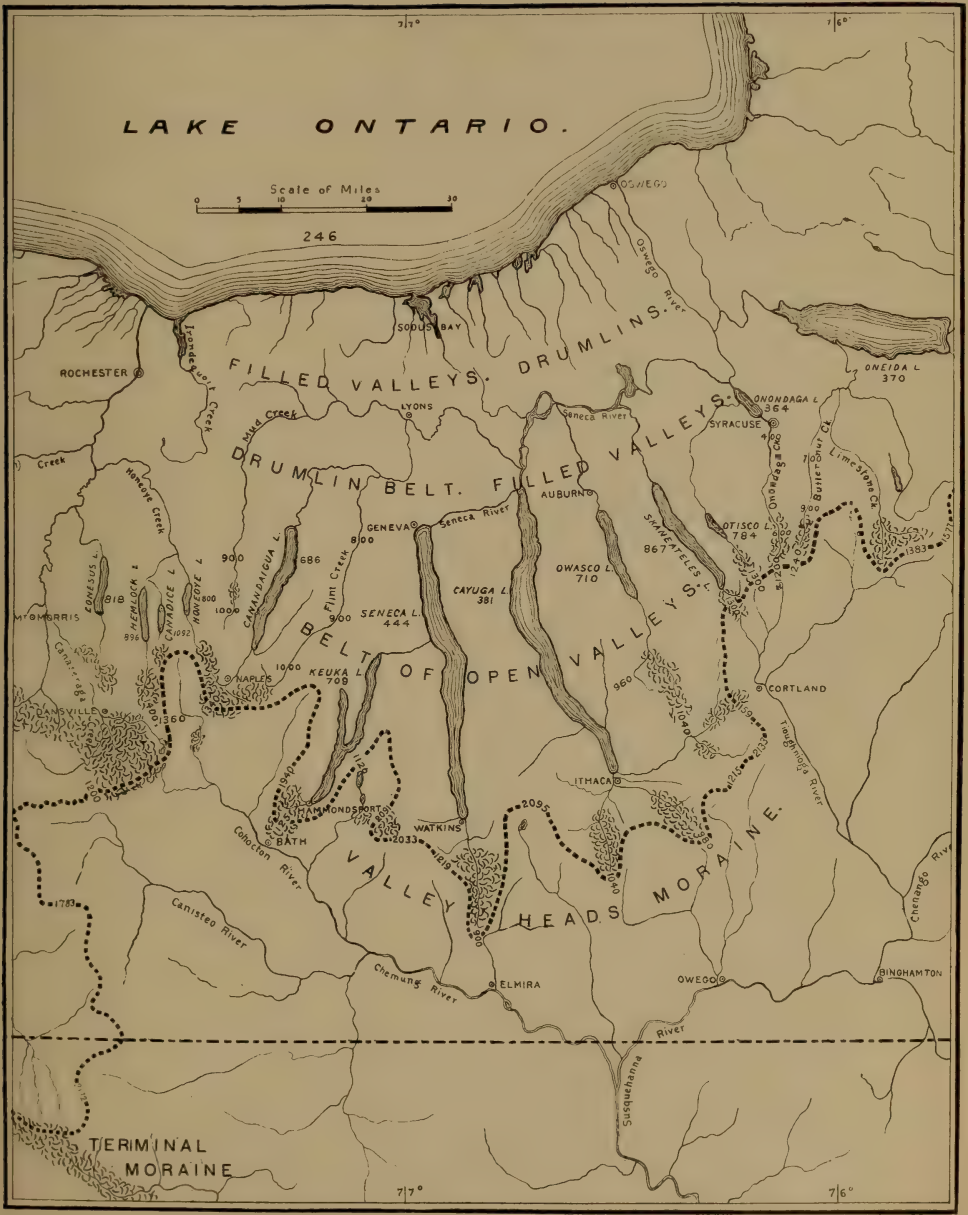
*Some suggestions of the history may be found in the following writings:

A. W. Grabau: In New York State Museum Bull. No. 45, 1891.

R. S. Tarr: "The physical geography of New York state." 1902.

M. R. Campbell: Geographic development of northern Pennsylvania and southern New York." Bull. Geol. Soc. Am., vol. 14, 1903, pp. 277-296.


LAKE ONTARIO.
Scale of Miles
0 5 10 20 30
246
77°
76°
OSWEGO
Oswego River
SODUS BAY
ROCHESTER
Irondequoit Creek
FILLED VALLEYS.
DRUMLINS.
LYONS
Mud Creek
Creek
Seneca River
DRUMLIN BELT.
FILLED VALLEYS.
ONEIDA L. 370
ONONDAGA L. 364
SYRACUSE
Onondaga Ck.
Butternut Ck.
Limestone Ck.
AUBURN
GENEVA
Seneca River
Honeoye Creek
CONESUS L. 818
HEMLOCK L. 896
CANADICE L. 1092
HONEOYE L. 800
CANANDAIGUA L. 686
Flint Creek
SENECA L. 444
CAYUGA L. 381
OWASCO L. 710
SKANEATELES L. 867
OTISCO L. 784
MT MORRIS
BELT OF OPEN VALLEYS.
KEUKA L. 709
NAPLES
DANSVILLE
Canaseraga Creek
HAMMONDSPORT
BATH
WATKINS
ITHACA
CORTLAND
Tioughnioga River
Cohocton River
VALLEY HEADS MORAINE.
Canisteo River
Chemung River
ELMIRA
OWEGO
BINGHAMTON
Chenango River
Susquehanna River
TERMINAL MORAINE
1783
1360
1200
1940
2033
1219
2095
900
1000
960
1040
1159
2133
1215
1383
1577
1240
1120
700
600
400
1000
800

PHYSIOGRAPHIC BELTS IN CENTRAL NEW YORK

Adverse argument from observed phenomena—Origin and basis of ice theory.—The suggestion of deep ice erosion as the cause of the Finger Lakes basins was definitely published by Lincoln [*] in 1892 and in 1894 by Tarr.[†] The argument is the discordance of the smaller tributary valleys in relation to their north and south trunk valleys. No other evidence of ice erosion has been given, and it is admitted that the broad intervalley ridges have not been severely eroded, since transverse valleys occur both open and drift-filled, and that the drift is scanty in the wide belt which includes the several lakes. But it is assumed that the drift filling on the north is not sufficient to cause all the ponding of the waters, and that the valleys have been deepened and basined by ice erosion many hundreds of feet. The argument is essentially the same as for deep valley cutting in Norway or Alaska. As the writer views the matter, the advocates of the glacial origin of the Finger lakes should prove that ice did the work, or at least that it is possible for ice to do it, and not leave the proposition resting wholly on assumption. However, the writer will generously undertake to supply an argument that ice could not do the work, followed by positive proof that ice did not do it.[‡]

Stagnation of lower ice in the deep valleys.—The slopes of the valleys and of the entire land surface in the region of the Finger lakes is northward, or against the ice-flow. When the district was buried under the larger ice body the flow of the ice must have been chiefly or entirely a flow of the upper layers down the sloping surface of the glacier. The ice in the depths of the larger valleys was probably inert or stagnant, and served as a bridge over which the upper ice traveled. When the ice was at its maximum, reaching the terminal moraine in Pennsylvania, the thickness of the mass over Seneca and Cayuga could hardly have been less than 4,000 or 5,000 feet. The high and irregular land south and southwest of the valleys was an obstruction to the bottom flow. Another cause of resistance to flow of the deeper ice was due to the very important fact that the general ice movement during the greater expanse of the glacier was decidedly oblique to the valleys. These combined conditions—the depth of ice, the opposition of the land surface, and the oblique push on the ice body (from the northeast)—must have produced stagnation of the ice in the bottoms of the valleys.

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[*] D. F. Lincoln in Amer. Jour. Sci., vol. xliv, 1892, pp. 290–301.

[†] R. S. Tarr in Bull. Geol. Soc. Am., vol. 5, 1894, pp. 339–356. The latter writing contains a bibliography on the subject.

[‡] Since these lines were written Professor Tarr has published an article, "Hanging valleys in the Finger Lake region of central New York," Amer. Geol., vol. xxxiii, May, 1904, pp. 271–291, in which he argues against glacial erosion of Cayuga valley, using some of the facts and arguments presented in this paper. This is a reversal of the opinion expressed in "The Physical Geography of New York State," 1902, p. 180, where he says: "The conclusions stated in my earlier paper have stood the test of much more extended studies, so that after seven years I am even more fully convinced that the two larger lakes owe their depth below the lake surface in large measure to ice erosion, and that they are in the nature of rock basins. Additional facts have been brought to light in support of this theory and none opposed to it."

The deficiency of drift filling in the deeper or more open sections of the Finger Lakes basins—in other words, the existence of the basins themselves—suggests comparative stagnation of the bottom ice in those sections. The great burden of subglacial drift was dropped along the drumlin zone (see plate —) at the north ends of the basins, where the transporting power of the ice lost efficiency. The low-lying but very heavy drift deposit north of the lakes, and which forms their northern barrier, was deposited previous to the retreat of the ice border along that belt, for it is crowned with drumlins which represent the molding by ice of some depth and at some distance from the edge. It should be clearly understood that the drumlin belt filling is not terminal moraine, but subglacial or ground moraine, which the ice sheet rubbed into the valleys and subsequently overrode. If the deeper ice had possessed much movement it would have swept the drumlin belt drift filling farther southward into or entirely through the upper parts of the valleys.

During both the earlier and the later stages, when the ice front was resting at the zone of the recessional moraine which now blocks the valleys and forms the present valley heads and water parting (see plate 21), the essential condition of the deeper ice was probably not unlike the former stage. The direction of flow was in line with the valleys, but the depth and pressure were less and the propulsion of the mass from the northward was not so forceful. It does not seem possible that any valley erosion could occur when the ice front was as far south as the valley-heads moraine. Any glacial wear on the bottoms of the Finger Lakes valleys must have been during other stages of the glacier.

This suggestion of stagnation of the deepest ice applies in less degree to all the smaller Finger Lakes basins.

Lobations of the ice front in the valleys.—The only stage during which it is at all reasonable to suppose that the valleys could have suffered ice erosion is that phase of ice advance and retreat when the ice was thinner and the front formed lobations in the valleys. There never were any stream or valley glaciers in the Finger Lakes valleys. This important fact seems to have been overlooked. Valley glaciers are drainage phenomena and do not flow uphill; neither do ice fields push glaciers uphill. When the ice front was south of the divide, on south-sloping surface, tongues from the ice front may have pushed forward down the valleys; but north of the divide the ice front had reentrants on the ridges and merely lobations in the valleys. Consideration of the mechanics of the glacier will show the necessity of this. The valley lobes represent a small amount of concentration by the flow from the higher ground either side of the valley, but they are chiefly due to the relatively slower melting of the deeper portions of the front.

Effect of deep waters facing the ice.—Probably during the advance of the ice sheet, and certainly during its retreat, all the valley lobes were fronted by deep glacial lakes. It has been questioned whether the valleys did not have reentrants in the ice front instead of lobations. In any case, the water was unfavorable to elongation of the lobes, due to its melting effect, and unfavorable to ice erosion on account of its buoyant effect. The earlier glacial waters had a depth in both Cayuga and Seneca of over 1,000 feet, while the Warren waters, during the withdrawal of the ice from the valleys, had a depth of over 800 feet in Cayuga and greater in Seneca.

The detrital deposits left in the waters which faced the retreating ice give no evidence of having been formed along the margin of ice tongues, and the drainage lines down the valley walls show no diversion due to ice occupation.

Whatever was the kind and amount of work by the ice in the Finger Lakes region, it was only that of a continental ice sheet and not that of stream or alpine glaciers.

No erosion in front of zone of deposition.—The existence north of the lakes of the ground moraine valley-filling crowned with drumlins has been referred to above. Perhaps one might regard this deposit as an early terminal moraine overridden by later ice advance. Certainly it is not terminal drift of glacial recession. But, whatever the view as to its origin, it proves the transportational impotency of the ice along that zone, and it is unreasonable to suppose that the lower ice, on a rising slope, could effectively erode in front of this zone of deposition.

It therefore seems impossible that the ice body which left the drumlin belt filling could have eroded the Finger Lakes basins. Of any earlier and more powerful invasion than that of the Wisconsin ice sheet we have no evidence whatever in this region.

Absence of moraines in the basins.—There are no conspicuous moraines in the Seneca or Cayuga valleys between the heavy deposits left at the receding front, which now form the valley heads, and that which carries the drumlins and constitutes the blockade on the north. There are no pronounced valley moraines except at the valley heads. For some 50 miles, the stretch between the two deposits named, the valley walls are comparatively free from localized drift. This absence of recessional moraines is a surprising and important fact. Some accumulations may be covered by the deep lakes; but surveys do not reveal them, and the lakeless valleys and those with only shallow lakes are also characterized by general absence of valley drift and the smoothness of the valley walls. This is inconsistent with the idea of erosion. The only explanation seems to be that the ice contained little drift in front of the drumlin belt zone of deposition, or that the valley ice was inactive and melted back without long pause. It is not thought possible that there could have been any serious erosion by valley lobes, saying nothing of "hundreds of feet" of cutting, without leaving conspicuous piles of debris, even in the presence of the glacial waters.

Small volume of the valley-heads moraine.—The total volume of the valley-heads moraine, after making liberal allowance for the valley train drift south of that moraine and the fine material carried to the sea, is probably no more than should have been gathered by the ice from the supply of weathered material or geest which the ice found ready to its grasp in the district immediately northward. The valley-heads moraine is probably much less in amount than the mass of drift lying in the drumlin belt on the low ground between the Finger lakes and lake Ontario, and there are no heavy moraines south of the valley heads. Where is the immense volume of drift which would have been produced by excavation of the valleys to depths of hundreds of feet, by the Wisconsin or any other ice sheet?

Idea of rock basins an assumption.—No real evidence has ever been presented to show that the lakes are not entirely due to barriers of drift; or, in other words, that the rock bottoms of the valleys are not graded from their sources, south of the present valley heads, to the Ontario valley or to their trunk valleys. In figure 4 is shown the relation in vertical plane of the bottoms of Cayuga, Seneca, and Ontario valleys at the present time. This shows a gradient from the deepest part of Seneca (somewhat south of the middle of the lake) to the abyss of Ontario of about 5 feet to the mile. Any filling of drift in the Seneca basin that would reduce this gradient for the rock valley may be offset by the probable drift in the Ontario basin. There seems to be nothing in our knowledge of the lake basins inconsistent with the idea of preglacial free northward drainage. Well borings will probably prove the fact of graded valleys of originally high gradient.

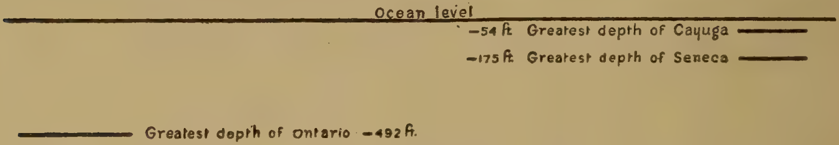
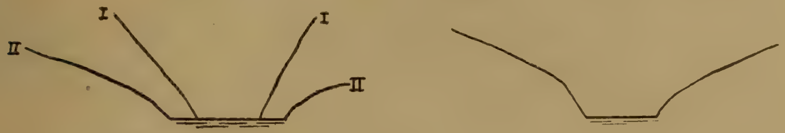

Ocean level
−54 ft. Greatest depth of Cayuga
−175 ft. Greatest depth of Seneca
Greatest depth of Ontario −492 ft.

FIGURE 4.—*Diagram showing Vertical Relation of Cayuga and Seneca Valleys to Ontario Valley.*

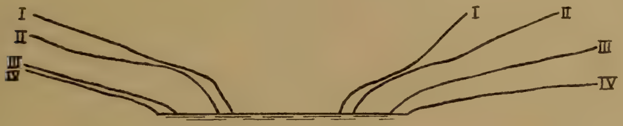
Vertical scale about 100 times horizontal.

Convexity of valley sides.—Cross-sections of the Finger Lakes valleys (figure 5) show convex valley slopes, not the concave profiles and U shape attributed to ice-worn valleys (see page 28). It would seem unreasonable to claim that the glacier cut hundreds of feet merely at the bottom, and not enough along the sides, in soft shales, to produce concave profiles of the valley walls.

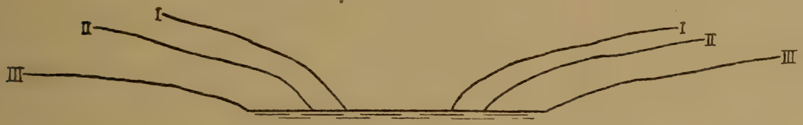


Canandaigua valley.
I. Section at head of lake.
II. Section at Long Point.

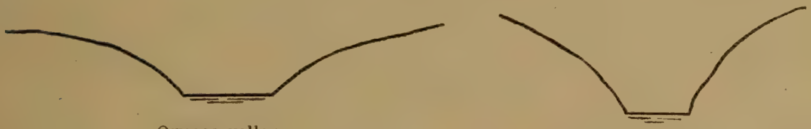
Keuka valley.
Section at Grove Spring



Seneca valley.
I. Section 4 miles from head of lake.
II. Section 1 mile south of North Hector.
III. Section at Lodi.
IV. Section 4 miles north of Willard.



Cayuga valley.
I. Section 2 miles from head of lake.
II. Section 4 miles north of Trumansburg.
III. Section at Aurora.



Owasco valley.
Section at Ensenore, 3½ miles from head of lake.

Skaneateles valley.
Section at Glen Cove, about 4 miles from head of lake.

Figure 5.—*Generalized Cross-section Profiles of Finger Lakes Valleys, looking north.*

Plotted from the topographic sheets; the vertical scale 6.5 times the horizontal.

The profiles beneath the lakes are apparently harmonious with the convex profiles of the exposed walls. Other valleys without lakes show the bottom contours, with some filling. As should be expected, these are somewhat variable, but none of them are the typical U shape of the glaciated mountain valleys.

Rock cliffs.—A large part of the shores not only of Seneca and Cayuga, but of the smaller lakes as well, are nearly vertical rock cliffs. These may be regarded as the product of wave work on decomposable shales that are intersected with innumerable joints, but there is abundant testimony, of people living by the lakes and familiar with their features, to the existence of submerged cliffs and ledges. These might be attributed to wave work when the lakes had a lower level, before the differential northward uplift had lifted the outlets and so raised the water levels to the present planes. Moreover, there are cliffs, at least in the Seneca and Cayuga valleys, much above the present waters. These might be credited to the local high-level glacial waters which occupied the valleys during the ice retreat.

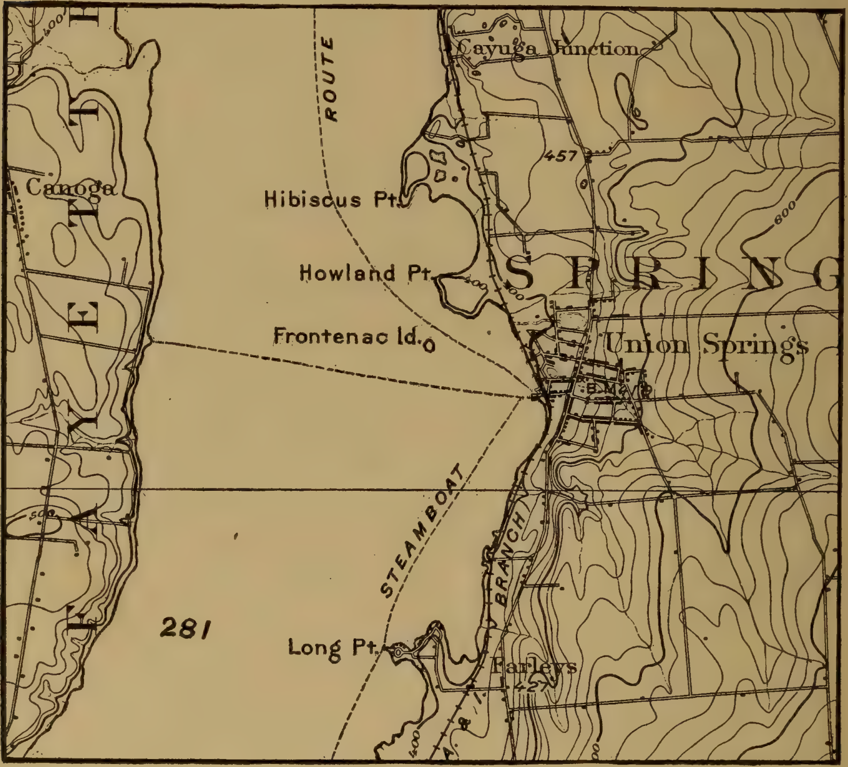

ROUTE
Cayuga Junction
457
Canoga
Hibiscus Pt.
600
Howland Pt.
S P R I N G
Frontenac Id.
Union Springs
B.M.
F A Y E T T E
STEAMBOAT
BRANCH
281
Long Pt.
Farleys
427
400

FIGURE 6.—*Map of Cayuga Lake Shores at Union Springs.*

From the topographic map.

Certainly rock cliffs, with or without angles, are not probable features by glacial abrasion, though they might be produced along the edges of stream glaciers aided by weathering. However, there were no stream glaciers in the Finger Lakes valleys. These cliffs are either the work of preglacial streams or of postglacial waves; they are not ice work.

Islands and capes of rock in Cayuga basin.—On the east side of Cayuga valley, at Union Springs, the shore has several sharp rock projections and one island of limestone, Frontenac island, the latter a half mile from shore. These features are shown in figure 6. The boat pilots say that other submerged rocks lie offshore. Such features are emphatically inconsistent with the idea of glacial enlargement of the valley at this point, as any severe effect of the glacial plane would straighten the valley walls. They are normal products of the work of atmosphere and water.

This point might properly be included under the next main heading as direct proof of non-erosion by ice.

Direction of the ice flow due to the topography.—The radial or digital attitude of the Finger lakes has been regarded by erosionists as a possible effect of the spreading flow of the ice sheet. If the valleys were radiating on downward slope the conception would not be entirely unreasonable, but they are spreading on upward slope. Undoubtedly the ice flow in the earlier and later stages may have been guided by the valleys. During the waning of the Ontarian ice body the spreading flow of the ice was up the radiating valleys; but this direction of flow was an effect, and not a cause, of the valley topography. The ice favored the lowest ground, and the deeper ice and stronger flow was naturally along the depression of which Seneca and Cayuga are the broad axis.

During the most forceful stage of glaciation the direction of flow was obliquely across the valleys.

Transverse valleys.—These have already been mentioned (pages 55–56). The transverse valleys are positive proof that the ice did not carve the more elevated topography. South of the divide, where the ice moved on downward slope, the transverse valleys and the irregular topography are proofs that the ice did not obliterate the relief features, even where it had greater fluency.

In the belt of the Finger lakes the transverse valleys exist, although somewhat obscured by drift filling. Along the divide and southward the preglacial topography is conspicuous. It would seem unreasonable to claim for a continental ice sheet the power of cutting trenches below some plane while above that plane the relief features are scarcely affected; yet the claim of glacial origin of valley discordance in central New York requires essentially that assumption.

Adverse philosophy.—The considerations presented above bear directly on the local problem, and they should alone be convincing of the fact that the Finger Lakes valleys were never deepened by ice erosion. The general theoretic argument against the competency of ice to deepen valleys has been purposely waived to this moment in order to give force to the concrete phenomena, but it should now be emphatically stated that the theoretic objections outlined on pages 25–31 apply with special force to this case. Theoretically there never could have been any effective cutting by ice in the deep bottom sections of Seneca and Cayuga, and really there are no phenomena nor features of any sort which require or even strongly suggest it.

Direct proofs of non-erosion.—Finally and conclusively we have in the valleys of the Finger lakes the same indisputable evidence of lack of ice erosion which has been described for the Niagara escarpment. In quarry exposures along the Seneca and Cayuga valleys and elsewhere it may frequently be seen that the upper layers of rock are weathered and rotted far beyond what is possible since the ice retreat. Abraded surfaces of fresh rock of the same kind, in the same localities, even in the same exposures, give comparison for postglacial decay which for till-protected surfaces is practically nothing.

Preglacially weathered rock in position may be recognized in a vast number of quarries or freshly cut rock sections throughout western-central New York. In the Finger Lakes district the rocks are chiefly shales, which are not favorable for preservation or discrimination of the old decomposition product. Fortunately there are numerous limestone quarries along the belt near the north ends of the valleys, and a few openings in the Tully limestone toward the upper end of at least the Cayuga valley; and limestone preserves the record in perfection.

To one on the ground the evidence is perfectly clear, but the photograph does not give the differences in color and texture nor show the finer effects of solution and corrasion. However, the facts are well shown in plates 22 and 23, which are only a few examples from many that might be given.

Plate 22 gives an example from the Onondaga valley similar to the plate 18, from Buffalo. This is a photograph of the east side of the Indian quarry, about 7 miles south of the center of Syracuse. The elevation is 580 feet and only about 120 feet above the bottom of the valley. The east wall of the valley rises 800 feet above the quarry. The preservation of the finest striæ and polishing of the limestones beneath even a thin mantle of till proves the incompetency of postglacial weathering to produce the degree of corrasion found in upper layers. In some parts of

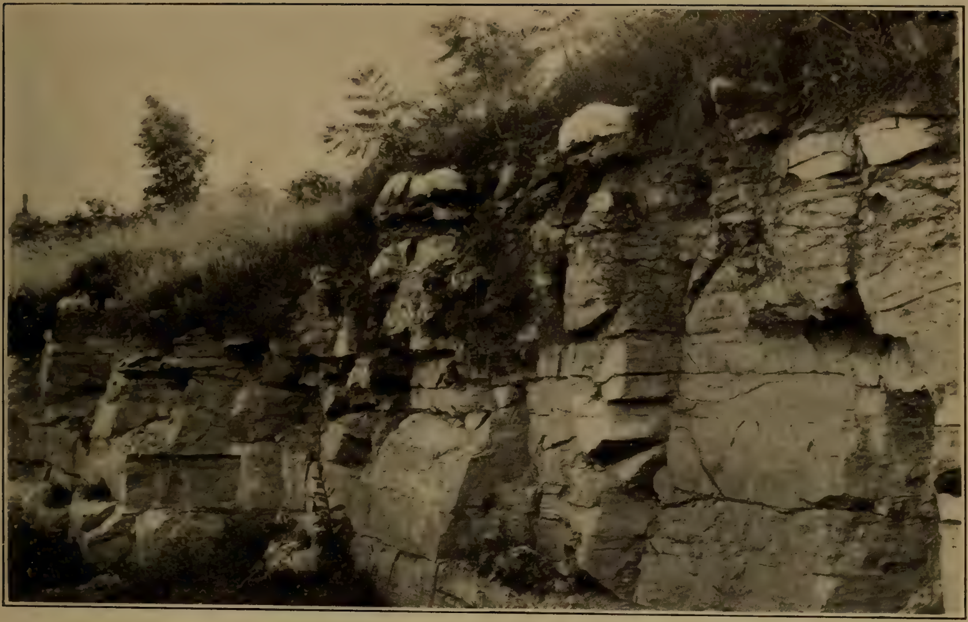


FIGURE 1.—GOODRICH QUARRY, ONONDAGA LIMESTONE, AUBURN, NEW YORK

Corroded beds in place at top

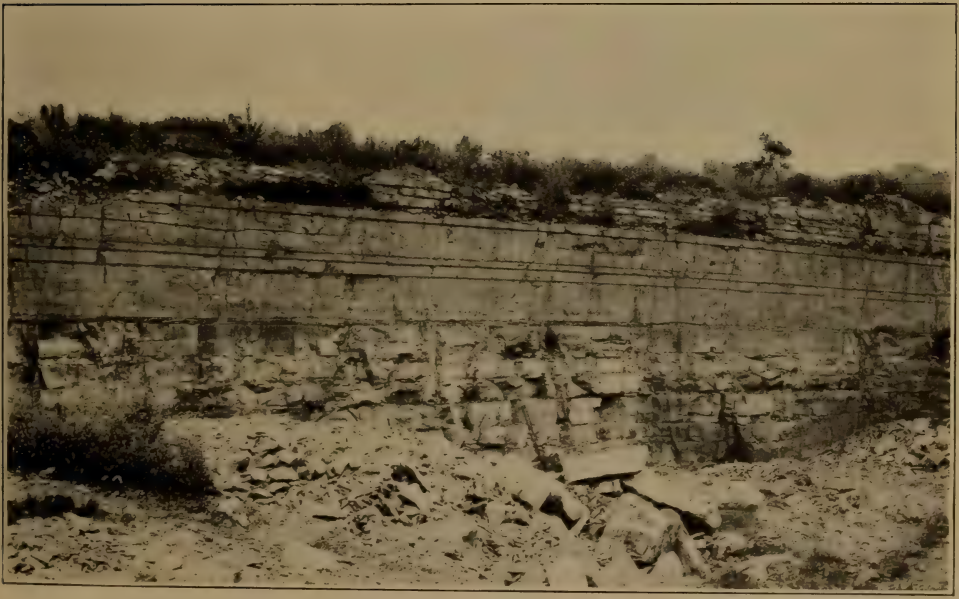


FIGURE 2.—INDIAN QUARRY, ONONDAGA LIMESTONE, 5 MILES SOUTH OF SYRACUSE, NEW YORK

Corroded beds in place at top

FAILURE OF ICE EROSION IN ONONDAGA AND OWASCO VALLEYS

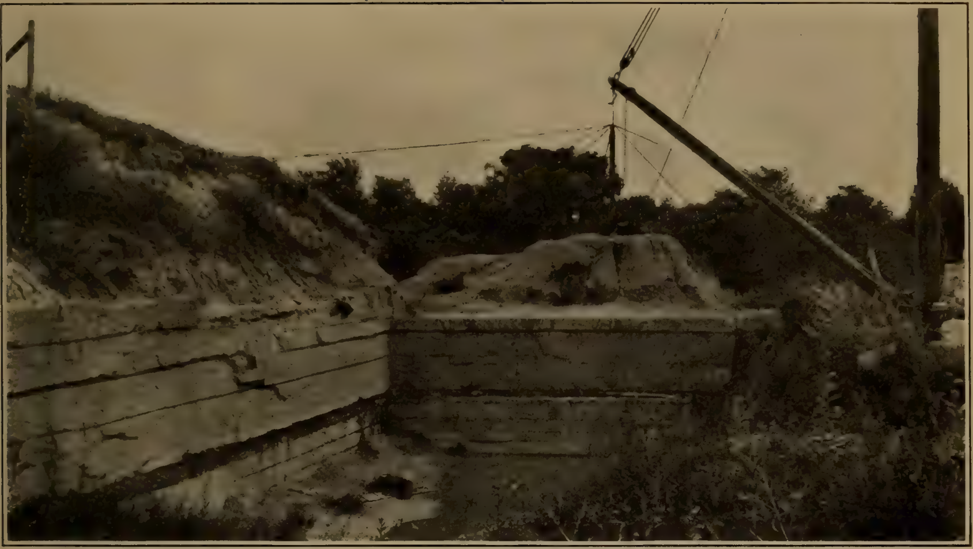


FIGURE 1.—THOMAS QUARRY, ONONDAGA LIMESTONE, WATERLOO, NEW YORK

Corroded bed glaciated but in place; buried in till

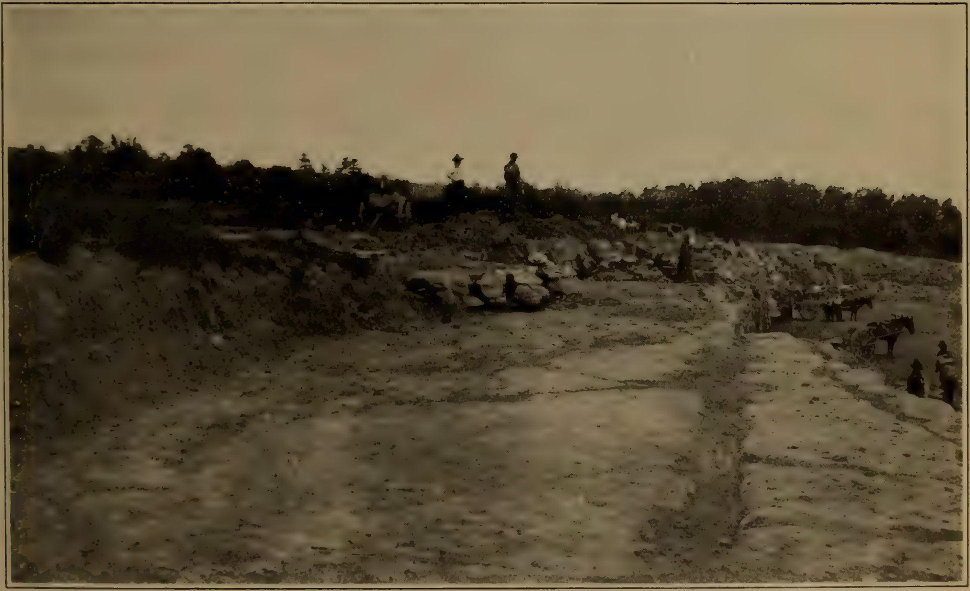


FIGURE 2.—PORTLAND CEMENT COMPANY'S QUARRY, TULLY LIMESTONE

This quarry is 6 miles north of Ithaca, New York. Extremely corroded beds glaciated, but in place. These are removed from the glaciated foreground, but show in the background

FAILURE OF ICE EROSION IN CAYUGA REGION

the Indian quarry the corraded layer shown in the view is removed and the till rests directly on the subjacent, firm, unweathered bed.

Plate 22, figure 1, is from the Goodrich quarry, near Cottage street, in the city of Auburn, lying in the northward continuation of the Owasco valley.

Plate 23, figure 1, is from the northside of the Thomas quarry, 1 mile south of Waterloo, in Corniferous limestone. About 2 feet of the base of the mound that looks like till, in the center of the view, is a bed of greatly corraded rock, but with the top of the weathered blocks well glaciated and with perfectly preserved polish. In the left of the view the same bed is shown quite unweathered, while on the west and south sides of the quarry the same bed, in perfect freshness, is buried under higher and weathered layers.

In the Cayuga valley the proofs of non-erosion by the ice are abundant. At Union Springs the limestone quarries yield the usual good evidence, as do also the gypsum pits. A good example of preglacial weathering is found in the Portland Cement Company's quarry, in Tully limestone, about 6 miles north of Ithaca, on the east side of the valley. Plate 23, figure 2, shows in the background remnants of a much corroded bed, about 4 feet thick, having the open joints filled with red, residual clay, Striæ on the tops of the corraded blocks and elegant glaciation of the firmer bed in the foreground of the view prove the lack of postglacial weathering. The large, open joints and seams in the subjacent beds are also filled with residual clay, so characteristic that the quarrymen recognized the material as different from the till. This quarry is only about 200 feet above Cayuga lake.

These facts of observation, which can be indefinitely multiplied and easily verified, prove beyond any reasonable doubt the failure of the glacial ice to remove even the superficial, weathered rock, even at low altitudes in the Finger Lakes valleys. It is plainly evident that the ice did not produce the valleys; it did not even enlarge them; and it would be unwarranted, in view of our knowledge of the mechanics of glaciers, to claim that the ice trenched below the present lake levels without effective cutting above those levels.

The most that can be reasonably claimed for the ice-work is that it smoothed off the intervalley ridges and also the valley sides. The valleys are stream valleys, like valleys everywhere, and only slightly modified by ice action.

Let us hope that assertions of the glacial origin or deepening of the Finger Lakes valleys (or any other valleys) will cease, and that former statements to that effect will be corrected.

History of the valleys—Preglacial conditions.—It does not seem proper to leave the subject of the Finger Lakes valleys with only a negative conclusion. Following is an outline of the sequence of geologic events, as the writer interprets the history.

A brief statement has been given on page 56. During the immensely long pre-Pleistocene time the region was probably exposed to subaerial erosion, and many changes must have occurred in land movement and attitude of the region, which had effects on the development of the drainage. The final result was the north-flowing streams and the hard-rock topography which we now find partially buried under glacial and lacustrine drift. A careful and patient investigation, without too much theorizing far in advance of facts, will probably discover some of the geologic events in the history, specially the later ones. Possibly there may be geologic factors involved of which we have not thought. The great desideratum for the study is data concerning the rock forms.

Preglacial drainage.—The regularity and parallelism of the northward drainage is a striking fact, doubtless explained in part by the uniformity in structure and attitude of the comparatively soft strata. It is believed that at least the stronger streams, such as the Senecan and Cayugan rivers, were graded to the Ontarian river, but with a high gradient.

The north-flowing streams were so closely spaced that the east-west streams were short and weak. Possibly in this may be found a hint of one cause of discordant drainage. Whatever may be the truth regarding this in other regions, in this area any serious discordance must be explained by the interaction of subaerial agents, with this qualification, that the very moderate amount of ice planing on the sides of the larger valleys in some places may possibly have accentuated the abrupt termination of some high-level side valleys, but this widening of the valleys has not been an important effect.

Ice invasions.—We may not be positive regarding the number of ice invasions in central New York. At present we have evidence of only one, the Wisconsin; but the certainty of several glacial epochs in the Mississippi region and the accumulating evidence of more than one epoch in the New Jersey-Long Island district, with the evidence of interglacial epochs at Scarboro Heights, Ontario, should make us watchful for records of multiple invasions here.

On first thought it might seem as if the occurrence of ice invasions previous to the Wisconsin would be favorable to the argument for ice erosion, but such is not the case. If the invasions were separated by long interglacial epochs, giving opportunity for mature stream work, the argument from topography could safely apply only to the latest invasion, and if the invasions were simply cumulative in their effects, then all the facts and reasoning as given on pages 57–64 would apply in the same way as to only one invasion. It is safe to discuss the history of the region as involving only the Wisconsin glacial epoch, for no evidences of any earlier and more forceful or extended sheet have been found. If the Wisconsin sheet failed to seriously erode it is unreasonable to appeal to earlier invasions, that were certainly smaller and weaker.

Effects of ice advance.—When the oncoming ice sheet transgressed our district, it might have had the same directions of flow and the same marginal form as during its retreat, which supposition is the most favorable to erosion. The transportational and erosional effects were doubtless the same in principle and general character, but there was certainly a difference in effect or degree. The ice found all the land surface, valley and hill, mantled in a thick sheet of residuum, which had to be cleared away before bed-rock could be affected. In addition to the local geest, the ice was already burdened with its enormous load of subglacial drift that it had gathered on its way; for it is not thought that any local glaciers could have affected this locality in advance of the continental sheet. With all its bottom load of debris, producing stagnation in the lower layers and acting as a buffer for the underlying rock, erosion must have been practically if not entirely nil. The advancing valley lobes were doubtless faced by lakes, as during their retreat. The upgrade which the ice had to climb is unknown, but it was certainly an uphill advance. The dropping of its basal drift at any line, as the drumlin-belt moraine, for example, would give no increased erosional power to the onmoving ice.

All considerations lead to the confident conclusion that the ice sheet during its advance did no erosional work. Its effect was to transport and distribute the debris which it had been forced to carry.

Conditions during maximum extent of the ice sheet.—We may suppose that as the valleys become filled with ice during the slow advance of the great ice body, and the latter rolled its front on to the higher ground southward, the ice was less and less diverted by the topographic features until finally the general movement, at least of the upper layers, was toward the southwest, and obliquely across the valleys of the Finger lakes, specially those east of Keuka. This conclusion regarding the direction of flow is derived from the trend of the great terminal and the recessional moraines, which were normal to the ice movement.

All our knowledge of the behavior of glaciers leads to the conclusion that the deeply buried ice in the valleys of the north-facing slope must have been comparatively stagnant and impotent. The thickness of ice over Seneca valley, when the ice front was at the terminal moraine in Pennsylvania, has been estimated by the writer as at least 4,000 feet.* Other estimates have made the depth much greater. Certainly the pressure due to depth was very great, and it was partly resolved into a potential pressure down the slope, or northward, and against the general movement. Three principles of ice movement were in play, namely, practical viscosity, rigidity, and shearing. The problem is too complicated to be here discussed, but the best conclusion is to the effect that during the burial of the region under the general ice sheet the deep ice was stagnant and erosion of the Finger Lakes valleys was impossible. The stagnating effect of the bottom debris must be taken into the account along with the mechanics of the clear ice.

Valley-heads moraine.—With the waning of the ice body the front receded to the line which connects the divides and moraines at the present heads of the Finger Lakes valleys. There the ice front lingered some time and accumulated the valley moraines. The front of the ice was probably lobate in the valleys, and there the morainal drift was concentrated; but it should be distinctly understood that the morainal masses at the heads of the Finger Lakes valleys were not made by "valley" glaciers, but by lobations at the edge of the great Ontarian lobe of the Labradorian ice body. When the moraine was forming at the present head of Seneca valley the depth of ice over the valley must have been over 2,000 feet, and the lower ice was doubtless inert.

The moraines at the valley heads can not reasonably represent erosion from the bottoms of the valleys for reasons which have been given. This is an important fact which writers have overlooked, and specially so since these are the only large drift accumulations which the advocates of valley erosion can refer to. They are too small in volume and too largely composed of far-traveled material to represent much valley cutting.

Effects of ice retreat.—From the line of the valley-heads moraine to the drumlin-belt filling, a distance of about 50 miles on the Seneca Lake meridian, there are no morainal deposits in the valleys which have been thought worthy of notice. Careful search by experts will doubtless find lines of marginal drift, curving over the ridges, which will be useful in proving the form and amount of lobation of the valley ice in its retreat.* The drainage courses down the slopes give no indication that they were initially determined by oblique ice margins.

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*"Glacial geology of western New York." Geol. Mag., Dec. iv, vol. 4, no. 402, December, 1897, p. 532.

It is apparent that the ice receded across the belt of the Finger lakes so steadily and rapidly as to leave no conspicuous marginal deposits. Surveys of both Seneca and Cayuga lakes prove that there are no large masses of drift beneath the water. None have been noted in any of the valleys, whether open or containing lakes. This absence of drift masses in the valleys north of the valley heads would seem to prove that no large amount of debris was produced by erosion after the ice border left the valley-heads moraine. In other words, there was no erosion of the valleys during the retreat of the ice, and consequently there was no erosion at any time. The positive proof of no serious erosion has already been given on page 64.

Local glacial lakes.—While receding northward over the north-sloping valleys the ice front acted as a dam to waters held in all the valleys. These local glacial lakes have been named and described in other writings.† They are referred to here not only because their episode forms part of the history of the region, but also because they had something to do with the valley forms. Below the highest level of these lakes, which was determined in each case by the elevation of the col across the moraine at the valley head, the slopes at the south end of the valleys felt the action of the laving waters. Some indefinite part of the smoothness of the slopes and the existence of the rock cliffs are due to the wave action. Along Seneca valley the waters of lakes Watkins and Newberry reached above 900 feet, or about 500 feet over the present lake. Lake Ithaca, in the Cayuga valley, southern end, had an elevation of over 1,000 feet, or about 600 feet above the present lake.

The deltas built by land streams on the valley slopes in the high waters of the glacial lakes are conspicuous for their form rather than their volume, and are the most striking proofs of the existence of these lakes.

The precise effects on the ice margins of the fresh waters of these deep lakes is not known. They probably facilitated the melting of the ice, and so helped to prevent strong lobation, and by insinuation beneath the ice they probably had a buoyant effect and helped to reduce the pressure of the ice on the valley bottoms.

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*Professor Tarr has told the writer that he has been able to trace some faint lines of marginal drift left by the receding ice in the Cayuga valley, which show merely lobations of the ice front.

†H. L. Fairchild: "Glacial lakes of western New York," Bull. Geol. Soc. Am., vol. 6, 1895, pp. 353-374; "Glacial waters in the Finger Lakes region of New York," ibid., vol. 10, 1899, pp. 27-68; "Glacial lakes Newberry, Warren, and Dana in central New York," Amer. Jour. Sci., vol. vii, 1899, pp. 249-263.

Drumlin-belt filling.—The heaviest deposit of drift in central New York is that belt lying north of the Finger lakes and which carries one of the most remarkable areas of drumlins in the world. It has not been recognized as morainal for the reason that it is so low-lying as to be buried or leveled by lake action. It forms the blockade to all the north and south valleys, both those with lakes and those without lakes today. The Flint and Bristol (Ganargua) valleys held shallow postglacial lakes which have been changed to swampy tracts.

The belt of drift lies deepest over the east and west outcrop of the soft Salina shales and north of the outcrop of the Helderberg-Corniferous limestones. It was all beneath the glacial waters of lake Warren and the slowly falling waters succeeding the Warren (Hyper-Iroquois); and all the area of the Sodus-Cayuga depression was under lake Iroquois during all the life of the latter (see plate 21).

It may be suggested that a large portion of this drift was rubbed into the valleys along the Salina outcrop during the early stages of the ice sheet, and thereby saved the more southerly part of the valleys (now occupied by the lakes) from great filling. The outcrop or low escarpment of the limestones was the most obdurate barrier which the ice encountered on the Ontario plain. The drumlins were probably formed during the closing stages of the ice. The lakes have spread their silts over the lowlands and partially buried even the drumlins, while vegetal deposits have continued the filling, and form the vast peat marshes of the Montezuma swamps and along the Seneca river.

Buried valleys.—The writer is not able to fully prove that the valleys are graded in rock and are merely dammed by drift, but all the available facts point to this, and it is believed that borings will so prove it. The assumption that any of the lakes have a rock barrier on the north is without any warrant in knowledge or in sound reasoning.

From the foot of the Finger lakes northward to near the Ontario shore the valleys are buried quite out of view beneath the drumlin-belt drift filling, but they partly reappear in the depressions along the Ontario shore. If the reader will spread before himself in order the Macedon, Pultneyville, Sodus bay, and Oswego sheets of the state topographic map he will see that the Ontario shore from Irondequoit bay eastward to Sodus bay, a distance of about 25 miles, has no embayments. The Medina rocks are here visibly continuous, and no large streams ever traversed this belt of land. They were diverted either westward to the Genesee (Irondequoit gulf) or eastward to the Seneca-Sodus valley. At Sodus bay is a great break in the shoreline, and a broad valley intersects the rock strata. This ancient valley is not less than 2 miles wide, but its walls are buried under drift, while 6 or 7 miles south from the Ontario shore the entire valley is hidden from view. The Sodus valley lies in direct line with the axis of the Seneca valley, and it is not a forced assumption that the Senecan river flowed through the Sodus valley, and that the Keukan, Flintian, and Canandaiguan rivers, lying westward, were tributary to the Senecan, probably bending eastward along the strike of the less resistant strata (see plate 21). The stream in the Mud creek (Ganargua) valley may have turned westward to join the Genesee.

Eastward from Sodus bay the maps show a series of bays or low ground. In order eastward these are: Port bay, Red creek, Black creek, Blind Sodus bay, and Fairhaven bay. The drift obscures the hard rock geology, but these sags probably indicate buried valleys. The precise correlation of these embayments with the Finger Lakes valleys is, of course, uncertain, but test borings will probably show that the Owascan, Skaneatelan, Otiscan, and Onondagan rivers occupied the buried valleys. The Cayugan river possibly united with the Senecan.

Greater glacial lakes.—The story of the later glacial waters has been partially told in other writings.* The important fact here is that not only all the glacial drift left by the receding ice in the lower parts of all the Finger Lakes valleys was deposited under water, but that north of the lakes all the drift under about 880 feet elevation was so deposited, either in lake Warren or its successors. In consequence of this fact the glacial debris is much distributed and blended with or buried under the lake deposits, and such morainal topography as shows at all is much subdued. The latter is chiefly kames or knolls of gravel.

Lake Warren came to extinction by the draining to lower levels through channels in the neighborhood of Syracuse, which carried the water eastward to the Mohawk valley. These falling waters have collectively been called Hyper-Iroquois. Finally, with the establishment of the outlet at Rome, came the long-lived lake Iroquois which has left the strong shore phenomena about the Ontario basin. When the ice blockade in the Saint Lawrence valley was finally lifted the region of the Thousand islands was about 40 feet below sealevel, and marine waters, the Ontario gulf, occupied the basin. As an effect of the northward uplifting of the entire region which has occurred since glacial time, and is still in progress,† the Thousand islands have been lifted toward 300 feet, and the possibly brackish waters of the Ontario gulf have been rinsed out to form lake Ontario, the latest representative of the series of water bodies in the Laurentian basin.

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*In addition to references given above, consult papers in the Twentieth, Twenty-first, and Twenty-second Annual Reports of the New York State Geologist. A map of lake Iroquois is in the twentieth report, and one of lake Warren in the twenty-second.

†G. K. Gilbert: "Recent earth movement in the Great Lakes region." Eighteenth Annual Report U. S. Geol. Survey, p. 604.

H. L. Fairchild: "Land-warping in western New York." Bull. Geol. Soc. Am., vol. 10, p. 66.

Present lakes.—Repetition is unnecessary here of the facts and conclusions given in the preceding pages. The principal factor in the genesis of the Finger lakes is probably the drift barriers, along with differential northward uplift. The postglacial tilting seems to range from 2 or 3 feet per mile in the Seneca valley to 5 feet per mile east of lake Ontario. We do not yet know the changes in land attitude which occurred before and during the Pleistocene. There may be some unrecognized factors in the problem, but the idea of "rock basins" has no firm basis in observation, and ice erosion has had but small effect on the region. It is granted that the valley slopes were rubbed by the ice to a smoother contour; that some minor side valleys may have been obliterated by filling; that it is possible, though not probable, that the ultimate and steep portions of some small side valleys might have been so effaced by the removal of the weathered walls of the main valley as to give a "hung up" appearance to the tributary valley.

The following table of altitudes of the central New York valleys and lakes gives the quantitative data bearing on the subject:

Vertical Relations, in Feet Above Tide, of the Central New York Valleys and Ontario Basin

	Height above sealevel.	Greatest depth of lakes.	Depth of lakes below sealevel.
Conesus lake	818	Shallow.	...
Hemlock lake	896	86	...
Canadice lake	1,092	86	...
Honeoye lake	800	Shallow.	...
Mud creek	1,000–900	...	...
Canandaigua lake	686	258	...
Flint creek	1,000–900	...	...
Keuka lake	709	179	...
Seneca lake	444	618	175
ONTARIO LAKE	246	738	492
Cayuga lake	381	435	54
Owasco lake	710	177	...
Skaneateles lake	867	294	...
Otisco lake	784	65?	...
Onondaga creek	600–400	...	...
Butternut creek	900–700	...	...
Limestone creek	800	...	...

The altitude for creeks given in the above table is that of the valley section lying in the Finger Lakes belt. The figures are given on the map, plate 21.

It will be seen that the western and eastern members of the lake series are comparatively shallow, and that drift damming is the reasonable explanation of their basins. This is equally true of Cayuga and Seneca when the depth of the buried section is considered. The Finger lakes are all properly classed as " morainal."

GENERAL SUMMARY

The first part of this paper discusses the question of glacial erosion theoretically, having special reference to alpine glaciers, with illustrations drawn from glaciated areas. The term erosion is restricted to signify removal of unweathered rock. After showing that the argument for erosion is inferential and chiefly based on uncertain topographic forms, an argument for erosion is formulated, which is then considered in detail and found inconclusive. A general negative argument based on recognized principles of glacier physics proves that bottom erosion of glaciers must be only by the slow process of abrasion, which is a self-checking process; that glaciers tend to widen rather than to deepen valleys; that glaciers can not deepen without widening their channels, and that all theory and observation lead to the conclusion that glaciers are ineffective agents in production of valleys or basins. The subject is then illustrated by examples drawn from areas of past and present glaciation in the northern hemisphere, with citation of observations and opinions by students of those areas showing the absence of any direct evidence of erosion, and that the chief claim for erosion is for Norwegian and Alaskan fiords and some Alpine valleys made by the physiographers on the ground of valley discordance. It is shown that such explanation does not harmonize the body of fact, but produces confusion. Lastly, it is shown that the ice-erosion argument for hanging valleys is illogical without proofs of the competency of glaciers, and that these features will undoubtedly be explained as normal product of atmospheric and stream work under conditions not yet understood.

The second division of the paper treats of the erosional phenomena in New York state as a critical area specially illustrating the work of a continental ice sheet. After showing that all observers agree on the slight erosional effect of ice on the Adirondack highland and in the Saint Lawrence valley, the area of western New York is found to yield the same result. Central New York, or the district of the Finger lakes,

is then studied at length. It is shown that the valleys of the Finger lakes were never occupied by stream or alpine glaciers, but only by lobations of the ice-front during the advance and retreat of the Laurentian ice body; that the flow of the ice was against the slope, or uphill, and during the most forceful stage was oblique to the valleys; that the lower ice was probably stagnant; that erosion was unlikely in front of the zone of deposition on the north; that the convex profiles of the valley walls prove the lack of valley widening, and that other features help to a theoretical conclusion adverse to ice erosion. Direct positive proofs of non-erosion are then presented in the existence in the valleys of remnants of preglacially weathered rock. The history of the valley formations and their later hydrography is then briefly outlined.

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HANGING VALLEYS

BY ISRAEL C. RUSSELL

(*Read before the Society December 30, 1904*)

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DEFINITION OF TERM "HANGING VALLEY"

The topographic features to which attention is here chiefly invited have been defined by G. K. Gilbert* as follows:

> "A hanging valley is a small U-shaped tributary to a larger valley, the floor of the smaller being considerably higher at the junction than the floor of the larger. Many of them are short, high-grade troughs, heading in cirques; some are mere cirques, without troughs—spoon-bowl hollows, high on the walls of main valleys. They are associated with other evidences of glacial sculpture, and the elevation of their floors is believed to result, as a rule, from the unequal erosion of valleys by glaciers of unequal size."

As stated by T. C. Chamberlin and R. D. Salisbury,† "when the lower end of a tributary valley is distinctly above the level of its main the former is called a "hanging valley."*

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*G. K. Gilbert: "Glaciers and glaciation." Harriman Alaska Expedition, vol. iii, New York, 1904, pp. 114–115.

†Geology, vol. i, New York, 1904, p. 155.

The first of these definitions restricts the term defined to the valleys of formerly glaciated regions, and ascribes to them a single mode of origin. As I hope to show in the following pages, a discordance in gradient between a main valley and its tributaries is not strictly confined to glaciated regions, and may result from one of several processes. For my present purpose, therefore, it is necessary to give a more comprehensive meaning to the term hanging valley than is done in the first definition referred to. The second definition is more general than the one framed by Gilbert, and does not imply mode of origin, but can perhaps be amplified in order to make it more graphic.

Provisionally and as used in this paper the generic term hanging valley may be understood to include any valley or valley-like depression the bottom of which is not in even adjustment with the bottom of the lower depression with which it unites and into which it drains, the passage from one to the other being by means of a slope of greater declivity than the gradient of the tributary valley, and in most instances precipitous—that is, hanging valleys are in striking contrast to the conditions normal to mature steam-eroded valley systems, in which, as was long since pointed out by Playfair, the branches of the system at their mouths are nicely adjusted to the level of the lower valley with which they unite.

The definition just presented takes account of present topographic conditions only, without reference to the manner in which the discordance in gradients referred to came about.

In attempting to define "species" under the hanging valley "genus" mode of origin may be taken as the leading criteria, and more or less conspicuous differences in hanging valleys produced by the same agency suggest the recognition of "varieties."

CLASSIFICATION

ENUMERATION OF SPECIES

Our present knowledge of hanging valleys seems to warrant their provisional classification under four species, namely, stream-formed, ocean-formed, diastrophic, and glacier-formed.

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*The nature and mode of origin of hanging valleys has been discussed by W. M. Davis in an article entitled "Glacial erosion in France, Switzerland, and Norway," in Boston Society of Natural History Proceedings, vol. 29, 1900, pp. 273-321. To the bibliography presented in this paper the following titles of subsequent publications treating of hanging valleys may be added:

W. O. Crosby: "The hanging valleys of Georgetown, Colorado." Technology Quarterly, vol. xvi, 1903, pp. 41-50.

Ralph S. Tarr: "Hanging valleys in the Finger Lake region of central New York." American Geologist, vol. xxxiii, 1904, pp. 271-291.

STREAM-FORMED HANGING VALLEYS

During the development of a river system a master stream may deepen its valley more rapidly than certain of its tributaries are able to keep pace, as has been explained by W. M. Davis and others, and the tributary valleys become discordant in gradient in reference to the main valley with which they unite. The various ways in which such a result is produced are well understood and need not be reviewed at this time.

An example of a hanging valley due to stream erosion was recently pointed out to me by M. S. W. Jefferson, near Ypsilanti, Michigan. In this instance the Huron river, in deepening its channel, left a long narrow point of land projecting from one side of its valley, and on the surface of this cape-like projection and transverse to it is a segment of an old channel made by the Huron when flowing about 40 feet higher than now. This fragment of an abandoned stream channel is now a hanging valley, and at each of its ends there is a precipitous descent to the present flood-plain of the stream that eroded it.

On the border of the Huron valley, about 5 miles east of Ypsilanti, as described by Isaiah Bowman,* there is a locality where the Huron river in broadening its valley cuts into the upper portion of one of its own tributaries. In this instance the portion of the tributary valley which was " captured " and the neighboring portion of the abandoned segment of the same valley respectively, were left " hanging " in reference to the valley of the Huron, and illustrate a process by which a conspicuous discrepancy between the bottom of a main valley and the bottom of a tributary valley may be brought about.

Each of the examples just cited may, as it seems, be logically classified as varieties of hanging valleys due to stream erosion.

OCEAN-FORMED HANGING VALLEYS

When a valley, and particularly one with a steep gradient, is tributary to the ocean, and a landward migration of the ocean shore occurs through the action of waves and currents, the distal end of the valley and its bordering uplands, may be removed, leaving its abbreviated up-stream portion opening in the face of a sea cliff and its draining stream, if one is present, discharging by means of a cataract into the sea. The portion of a valley thus truncated would have the characteristic topographic features of a hanging valley, and might be of stream or glacial

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"A typical case of stream capture in Michigan." Jour. Geol., vol. xii, 1904, pp. 326–334.

origin or have resulted from the combined action of these two and possibly also of other agencies.

Examples of valleys which have been abbreviated in the manner just referred to and left suspended above the ocean are present on Unalaska island and open to the sea several hundred feet above its level.* Other similar examples might be cited, but it is evident that whenever a sea cliff recedes at a more rapid rate than streams, or glaciers, on the adjacent land can deepen their channels and at their mouths maintain a position at sealevel, hanging valleys must result.

DIASTROPHIC HANGING VALLEYS

A fault may cut across a valley so as to produce a steep descent in its bed, and thus cause one of its segments to become a longitudinal hanging valley in reference to the next lower segment. An example in line with this suggestion has been described by W. O. Crosby † near Georgetown Colorado.

If a region with stream eroded or other valleys becomes broken by faults so as to produce block mountains, or when during periods of rest in the growth of such faults valleys are eroded, it is evident that examples of discordant gradients of the nature of those under consideration may result. Examples of such diastrophic hanging valleys are abundant in the Great basin, which open into broad desert valleys or basins, high above their bottoms, although in many, and perhaps most, instances the steep descents at their mouths are concealed beneath alluvial deposits.

It needs but a suggestion to make it clear that the upheavel of a bold coast in a state of mature topographic development or occupied by tidal glaciers might transform the valleys previously deepened approximately to baselevel into hanging valleys opening in the rim of an ocean basin.

The three "species" of hanging valleys to which attention has just been directed would probably be considered as "imitative forms" by persons who hold that the recognition of a glacial origin in the definition of a hanging valley is essential, or consider that hanging valleys are in themselves evidence of former glaciation. If, however, we assume that peculiarity of togographic form is the leading fact expressed by the term hanging valley, it is consistent and legitimate to recognize under that term the discordances in slope produced in the several ways just cited.

GLACIER-FORMED HANGING VALLEYS

As has been clearly shown by Gannett, Gilbert, Davis, and others, hanging valleys would result in case a main valley glacier eroded its bed more deeply than a tributary glacier deepens its bed. The difference in the depth of such valleys, after the glaciers which shaped them had melted, would represent the excess of erosion of the receiving glacier over that of its tributary. This simple and one may say self-evident explanation of the origin of the numerous hanging valleys of glaciated mountains is seemingly complete and satisfactory if the large amount of glacial erosion it implies in numerous instances can from other evidence be proven to have occurred. This matter will be reverted to below. In the study of glaciated hanging valleys, however, the question arises: Are there not other processes by which glaciers can produce similar topographic results? To aid search in this direction, at least six suggestions seem pertinent, and are embodied in the following paragraphs:

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*G. K. Gilbert: "Glaciers and glaciation." Harriman Alaska Expedition, vol. iii, New York, 1904, p. 185.

† "The hanging valleys of Georgetown, Colorado." Technology Quar., vol. xvi, 1903, pp. 41–50.

Small glaciers sometimes originate on the sides of mountains or on the borders of deep valleys where, so far as can be ascertained, no previous depressions existed. Examples of such "mountain-side glaciers," as they may be termed,* are known on mount Rainier, Washington, and on the Three Sister peaks and mount Jefferson, in Oregon, and elsewhere. It is evident from inspection that typical mountain-side glaciers are engaged in excavating depressions for themselves, which, at an early stage in the process, have the essential features of cirques, and at a later stage develop a valley of the typical U-shaped cross-profile, flat bottom, etcetera, with a cirque at its head. These glaciers may be said to burrow into the mountain sides by headward extension, chiefly, as is judged, by "quarrying." The lower limit to which they are enabled to excavate their beds, or the local baselevel, is determined by melting. A glacier of the type referred to deepens its bed to this level, and, given time enough, extends it headward until a flat-bottom trench is produced. Should the glacier then melt, a hanging valley would be left, the mouth of which would open out on the slope on which the glacier originated. Such valleys are "hung up" in reference to the country which they face, but differential glacial erosion has no part in their production.

A mountain-side or valley glacier sometimes ends at the summit of a precipice, where it breaks off and descends in avalanches, to be recemented at the base of the escarpment or there melt, according to climatic conditions. In such instances it is evident that the glacier before being broken might excavate a cirque or trough according to the length of its duration, and on melting leave a hanging valley. In this case, as in the one cited above, the resulting valley is hung up in reference to the depression which it faces, and this depression may be a narrow or wide valley, a continental or an oceanic basin.

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*The class of glaciers referred to have, as it seems, at least in part, been previously termed "hanging glaciers."

The changes in topography produced by mountain-side glaciers in the ways just cited may be likened to the excavation of valleys by tidal glaciers, inasmuch as in each case a local baselevel is established above the bottom of a depression into which the glacier in each instance would have advanced if conditions had not intervened which led to the removal of its distal end.

The production of rock escarpments across young glacial valleys by the method of "quarrying," as outlined by Willard D. Johnson, so well illustrated in the glaciated canyon of the Sierra Nevada, Cascade mountains, and elsewhere, also results in breaking a valley or trough into parts, one of which is left hanging in reference to its next neighbor lower down. It may seem far-fetched to consider the examples just cited as hanging valleys, but in glaciated valleys like those of the Sierra Nevada, etcetera, the highest segment of a glaciated trough frequently leads to a cirque, and in many instances has essentially all the topographic features which pertain to normal hanging valleys on the sides of similar troughs. The only topographic difference between the two seems to be that the last "tread" in the giant stairway a valley glacier makes, and the hanging valleys recognized by Gilbert and others, is that the tributary enters the main valley at its head and in a direct continuation of its course, instead of from the side.

In case a glacier originates in the upper portion and is extended down the course of a previously stream-eroded valley, filling it, we will assume, to a depth of 1,000 feet for a distance of many miles, local glaciers may originate on the bordering valley slopes, either in previously stream-eroded gorges or on the precipitous valley side after the manner of mountain-side glaciers, and enlarge preexisting ravines or create new lateral troughs. Such lateral glaciers might become tributary to the main valley glacier, in which case they would have a baselevel of erosion determined by the level of the receiving glacier, less the thickness of the tributary. In this imaginary case, which, as it seems, could be paralleled in nature, the side glaciers would excavate valleys, which, if the ice should melt, would become hanging valleys, in reference to the main trough formerly occupied by the receiving glacier, but the discordance between the two would not be due entirely and possibly only to a small extent to differential glacial erosion.

As has been pointed out by several writers, a large valley glacier which advances down a previously stream-eroded valley tends in an efficient way to straighten and broaden it. By this process lateral valleys are abbreviated, and when the glacier melts a discordance in gradient between the main valley and its tributary valleys would become manifest. This result would follow under the process referred to, no matter whether the tributary valleys were occupied for a time by secondary glaciers or not.

Still another manner in which glaciers may give origin to hanging valleys without the aid of differential ice erosion is illustrated about the northern border of the Malaspina glacier, where several alpine glaciers are tributary to a widely expanded ice sheet at the foot of the mountains from which they flow. The surface of the feeding ice streams near their mouths are not at present well adjusted to the surface level of the receiving ice field, but make more or less sharp descents in order to join it. During a previous and higher stage of the glaciers, however, their surfaces were more nearly in adjustment than at present. The point I wish to make is that a tributary to a piedmont glacier would have its base-level determined by the horizon of the receiving ice field less the thickness of the tributary, and, given time enough, would excavate down to that level. Should the glaciers meet after this result had been reached, hanging valleys would appear about the border of the basin or plain formerly occupied by the piedmont glacier.

To summarize: There appears to be at least six sets of conditions or processes each of which may produce glaciated hanging valleys without necessitating a conspicuously great measure of differential ice erosion.

To generalize more widely, as I think is justified from the considerations presented in the preceding pages, there are at least five sets of conditions each of which may produce hanging valleys without the assistance of glaciers and at least six sets of conditions under which glaciated hanging valleys may originate.

Most common Type of Hanging Valleys

CHIEF CHARACTERISTICS

As is well known, hanging valleys are a characteristic feature of many formerly glaciated mountains, such as the Sierra Nevada, Cascades, the Alps, the Southern Alps, etcetera. In such mountains conspicuously straight or broadly curved trough-like valleys, U-shaped in cross-profile and several thousand feet deep, are of common occurrence and frequently have tributary glaciated valleys opening into them along their sides at elevations of perhaps 1,000 and in some instances 2,000 or more feet above their bottoms. In the most typical instances the gradients of both the receiving and tributary valleys are low, and the descent from the mouth of a tributary to the bottom of its main valley is precipitous and in alignment with the adjacent portions of the side of the main valley. Very commonly, too, the mouth of the tributary hanging valley is about on a level with the highest lateral moraine, or other evidence of glaciation, on the sides of the receiving valley, but this is not always the case.

DISCUSSION AS TO ORIGIN

It is chiefly in reference to the mode of origin of hanging valleys of the type just described that differences of opinion have arisen among students of glacial topography.

Having in mind the several processes by which glaciers may produce hanging valleys, as enumerated above, it seems evident that those of the type just referred to must have been produced in one of two ways or by a combination of the two methods: Either they have resulted from the differential ice erosion of the main valley and of its tributary, or a pre-Glacial drainage system has been modified by glaciers so as to have the characteristics referred to, or these two processes have been active at the same locality.

If the first of these explanations is accepted, it follows that the rock removed to form the portion of a main valley lying at a lower level than the bottom of a tributary hanging valley is a minimum measure of the amount of ice erosion in the main valley. What the maximum amount of ice erosion in such valley may be is not apparent and, as it seems, has not received serious consideration. Unless pre-Glacial erosion is admitted, however, in the case of such mountains as the Sierra Nevada and Cascades, the hypothesis of differential ice erosion to account for hanging valleys implies that far more rock has been removed by ice than is accounted for by the differences in elevation between a main valley and its tributary hanging valleys.

The hypothesis which essays to account for hanging valleys by the enlargement and modification of pre-Glacial stream valleys rests mainly for its support on the principle that a glacier developed in a main stream-eroded valley would not only tend to straighten and broaden it, and thus truncate the ends of tributary valleys, but establish a baselevel for lateral glaciers, and by determining the depth to which they would be able to erode lead to the origin of hanging valleys at the level of its surface, minus the thickness of the tributaries. Under this hypothesis also some differential ice erosion must be admitted, since other conditions being the same a thick glacier must be accredited with greater erosive power than a thinner one; but several qualifications would have to be considered in this connection in attempting a complete analysis.

One of the hypotheses before us, then, demands a vast amount of glacial erosion, while the other implies far less conspicuous results in this connection. In looking for criteria by which to test the two hypotheses there are evidently two chief directions in which search may reasonably be expected to yield assistance. These are, first, the topographic features due to removal of material in order to produce the valleys of glaciated mountains, and, second, the character, and especially the amount of material still in sight and recognizable, which was removed by glaciers and deposited elsewhere.

If the mountains in which hanging valleys are a common feature, owe the valleys—the excavations of which have given them their leading and characteristic features—wholly or to a conspicuously great degree to glacial erosion, or, on the other hand, have been shaped principally by stream erosion and only to a minor degree modified by glaciers, the study of the character, distribution, and interrelation of their valleys furnishes a basis for opinion.

I must freely confess that I am not in a position to thoroughly discuss this broad and far-reaching problem, but venture to direct attention to two localities which seem to furnish data bearing on the question immediately before us.

Throughout the major portions of the Sierra Nevada and Cascade range there are conspicuous evidences of erosion both by water and ice; but to the direct question: Did pronounced stream erosion precede the work of the glaciers? It is difficult with the criteria at present available to obtain a satisfactory answer. The conditions demanding consideration are complex, and the decidedly vigorous ice erosion which has occurred in many portions of the mountains referred to did much to erase the evidence pertaining to the nature of the pre-Glacial topography. Better localities for beginning the inquiry under consideration are, in my judgment, furnished by the mountains of the Great basin which bear records of a brief period of glaciation on their higher portions. For this purpose Stein mountain, in southeastern Oregon, is well suited.

DETAILED STUDY OF KIEGER CREEK CANYON AS A TYPE

Stein mountain* is a typical block mountain, with a bold eastern face, bordering a fault or a series of faults, and is inclined gently westward. Its elevation is about 9,000 feet, and it rises approximately 5,000 feet above the basin at its eastern base. Starting at the crest of the tilted block and leading westward are several deep canyons, one of which, Kieger Creek canyon, contains unmistakable evidence of glaciation in the upper 4 or 5 miles of its course. The canyon is comparatively straight, and is simple in its topography. In its upper portion its bold northern border is a great precipitous wall, without lateral valleys or alcoves, but its southern border is conspicuously irregular and has four or five cirque-like hanging valleys arranged along it and about 1,000 feet above its bottom. These hanging valleys are less typical than in many other instances, and at their mouths the main valley widens and the steep descents leading from them to the receiving valley are within recesses, and do not form a part of the main wall of the larger valley. At the present time the snow melts in the main valley, even at its head, each summer, but lingers so as to form perennial banks in the cirque of each of the tributary hanging valleys on its southern wall.

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*The facts here presented in reference to Stein mountain are from Bull. no. 217, U. S. Geol. Survey, pp. 16–17.

The question is: Was Kieger canyon in existence previous to the formation of glaciers on Stein mountain, and does the evidence point to deep stream dissection of the mountain before glaciers appeared, or was it excavated entirely by the glacier that occupied it, less the insignificant amount of post-Glacial stream erosion that has occurred?

The facts most suggestive in this connection are: Kieger canyon is prolonged for some 20 miles below the locality where the lowest evidence of glaciation is discernible, and is not floored with coarse debris, such as occurs downstream from the extremities of existing valley glaciers. No alluvial terraces are present to show that conspicuous variations in the load of Kieger creek have occurred, such as are present in many valleys which have held glaciers in their higher tracts. There are no recognizable terminal moraines anywhere in the canyon and almost a complete absence of lateral moraines. The evidence of the former presence of a glacier in the upper end of the canyon is furnished principally by a noticeable increase of width in the portion formerly occupied by ice and a change from nearly vertical walls to an U-shaped cross profile.

If we assume that Kieger canyon owes its depth below its hanging valleys to ice erosion, it must be remembered that its chief supply of ice came from the small glaciers on its southern side, as there is no well-defined cirque at its head and no other gathering ground for snow, except the nearly straight and unbroken surface of its precipitous northern wall—that is, the highest lateral glacier was enabled to excavate a valley some 300 or 400 feet deep, but on turning at right angles to its upper course and being reinforced to a slight extent by the snow in Kieger canyon, above where the change in direction occurred, it was at once enabled to erode a canyon to a depth of 1,000 feet. Such an assumption, while called for by the hypothesis of differential ice erosion to account for hanging valleys, does violence to what is known to be the habit, so to speak, of glaciers and is manifestly untenable.

The facts presented by Kieger canyon, on the other hand, are consistent with the idea that a deep water-cut trench existed before the small glaciers from the south entered it, and that it has experienced what may be termed a small degree of glacial erosion. This conclusion finds support also in the fact that, so far as has been discovered, none of the other canyons on the Stein mountains show evidence of glaciation. Kieger canyon heads in the highest portion of the upturned block in which it has been excavated, but the advantages thus assured in reference to snow accumulation are not conspicuous. Seemingly the conditions were so delicately adjusted that a glacier was formed at the head of Kieger canyon, but not in neighboring canyons. This condition of delicate adjustment of elevation and topographic conditions to the climate of the region is now manifest by the presence of perennial snow banks in the shelter of northward-facing cliffs on the border of Kieger canyon and their absence on the borders of the neighboring canyons.

Considering all the evidence and endeavoring to make a just allowance for personal equation, it seems justifiable to conclude that Stein mountain was deeply dissected by streams previous to the Glacial epoch, and that during that epoch snow accumulated on its summit portion and gave origin to glaciers on the south side of Kieger canyon, near its source. These small glaciers descended into the canyon and formed a trunk glacier 4 or 5 miles long. With the amelioration of climate as the Glacial epoch drew to a close the ice melted out of the canyon, but still lingered in the form of small glaciers in the cirques under the shelter of its south wall and at the localities where perennial snow is still present. The small side glaciers high on the wall of the canyon excavated alcoves for the reason that in the earlier portion of their existence their ice during a certain stage in its advance gained the precipitous slope of the main canyon, there broke off, and descended as avalanches, thus having a lower limit of erosion analogous to a local baselevel established, and later, when Kieger canyon was occupied by ice, the side glaciers became adjusted to its surface level and had the downward limit to which they could excavate determined by this cause. Again, when the ice melted in Kieger canyon, the side glaciers continued their work in the same manner as during their earlier stage. The resulting topographic change was mainly the production of high lateral alcoves or cirques on the side of the main canyon, which constitute, but are not typical examples of, hanging valleys.

In the case of Kieger canyon, as I have attempted to describe, lateral glaciers entered a main valley which essentially had no cirque or other gathering ground for snow of its own, and that the side glaciers can not consistently be held accountable for any considerable share of the work required to excavate it. This case does not stand alone, and there are at least some reasons for thinking it may prove to be typical rather than exceptional in the topographic history of glaciated mountains.

Another example of topographic conditions similar to those just cited is furnished by the canyon of Rush creek, near Mono lake, California. In the case of Rush Creek canyon, as is well shown on an admirable map of the basin of Mono lake made by Willard D. Johnson,* a deep horseshoe-shaped valley is present at the eastern base of the Sierra Nevada, which has four or five hanging valleys arranged along its precipitous outer margin. Two of the tributary valleys were formerly occupied by valley glaciers, and where they enter the main valley, at right angles to its course, there is a steep descent of about 1,600 feet, and two others of the tributary hanging valleys are little more than cirques, and enter the main valley at about the same horizon as the larger tributaries and also at about the level of the highest lateral moraines in the lower valley. The main valley had essentially no source of snow supply except the contributions from its own hanging valleys, and it is inconsistent with the known behavior of glaciers to assume that the tributary glaciers from the lateral valleys abruptly changed their direction of flow and at the same time and at localities in definite alignment one with another deepened their troughs at least 1,600 feet in excess of their upstream portions. On the contrary, the facts just referred to are in harmony with the view that the horseshoe-shaped portion of Rush Creek canyon, and at least the larger of its tributary valleys, were in existence previous to the development of the glaciers of that region and gave direction to the glaciers which occupied them. In this instance, as in the case of Kieger canyon, pre-Glacial topographic conditions seem clearly to have given direction to the flow of the ice which occupied the canyon and to have been modified by ice abrasion to only a secondary degree.

Returning to the consideration of Stein mountain, it is situated about 180 miles east of the Cascade range, is of about the same height as that range, is composed of similar rocks, and, so far as can now be judged, was upraised at about the same time that volcanic eruptions built the principal part of the larger mountains. It may therefore reasonably be assumed to have experienced the same climatic changes as the Cascade range, but in a less intense degree. Its history may, as it seems, be taken as a simplified example of the more voluminous and more complex records of events inscribed on the greater mountain with which it is somewhat remotely associated. I venture to assert, in part from personal observation, that certain other isolated mountains in the Great basin, as, for example, mount Newberry,* Oregon, and Jeff Davis peak, Utah, are similar to Stein mountain so far as their records of climatic changes are involved, and, as is well known, are similarly situated in reference to the Cascade range and the Sierra Nevada.

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* Israel C. Russell: "Quaternary history of Mono valley, California." Eighth Annual Report, part i, U. S. Geol. Survey, plate xvii. A description of Rush Creek canyon, etcetera, is contained in the same report.

RELATION OF PRE-GLACIAL EROSION TO HANGING VALLEYS

It is exceedingly difficult to formulate and duly evaluate the evidence just considered, but when it is correlated with other evidence, such, for example, as the facts presented by Le Conte and others, showing the occurrence of a Sierrian epoch of stream erosion preceding the Glacial epoch, the only consistent conclusion seems to be that the Sierra Nevada and Cascade ranges were deeply dissected by streams previous to their occupancy by glaciers.

In reference to hanging valleys, this conclusion favors the idea that they have been excavated on the sides of pre-Glacial canyons, chiefly because of the establishment of a baselevel of ice erosion in such canyons by large valley glaciers, which determined the lower limit to which the secondary glaciers on their sides could excavate, and does not favor the idea that differential ice erosion should be held accountable for the entire amount of discrepancy in depth between a receiving and its lateral hanging valleys.

FURTHER DISCUSSION OF ORIGIN OF GLACIATED HANGING VALLEYS

As stated on a previous page, two classes of evidence may reasonably be appealed to in seeking an explanation of the mode of origin of glaciated hanging valleys. One of them, namely, the topographic changes produced by excavation, has been briefly considered. The other, namely, the character and distribution of the material removed in order to make the excavation referred to and redeposited in recognizable form, remains to be reviewed.

If the hanging valleys of such mountains as the Sierra Nevada and Cascade ranges are due to differential ice erosion, as claimed by several geologists and geographers, it implies a vast amount of ice work. For example, a conservative estimate of the volume of rock necessary to fill the valley of lake Chelan up to the level of the hanging valleys on its borders is in the neighborhood of 50 cubic miles. To perform a similar task in several other valleys of the Cascade range and Sierra Nevada would require the removal of similarly great quantities of material. Several of these trunk valleys with hanging valleys along their sides are 40 to 50 or more miles long and their tributary hanging valleys from 1,000 to 2,000 feet above their bottoms. If glaciers excavated even the portion of these valleys which are situated at a lower level than the floors of their tributary hanging valleys, not taking into account the portions of the valleys above such horizons, it is legitimate and logical to demand that evidence be produced as to the disposition the glaciers made of this material.

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* Mount Newberry is described and named in U. S. Geological Survey Bull. no. 252.

In traversing such canyons as those occupied by Methow and Wenache rivers and the valley of lake Chelan, in Washington, or the Tuolumne and other similar canyons in California, one can not fail to be impressed with the fact that the amount of morainal material associated with them is insignificant in reference to the size of the excavations from which it was derived. In several typical instances the morainal material in sight or which may reasonably be assumed to be present, if spread over the glaciated surfaces of the canyons from which it was obtained, would, it is safe to say, form a layer only a few feet, and in most instances only a few inches, thick.

It can, perhaps, be claimed that the glaciers ground their grists so fine that the streams supplied by their melting carried it away and distributed it so widely that it is no longer recognizable; but glaciers carry fine and coarse material alike, and the coarse material should, in the instances under consideration, still remain where the glaciers left it. While there is no known ratio between the coarse and fine debris of glaciers, we know that in many instances conspicuous deposits of till, boulders, etcetera, are laid down by them. For example, in the case of the continental glaciers that formerly occupied the northern half of North America the moraine and till sheets are far more conspicuous than the records of abrasion left by the same ice sheets. So, too, in the case of many alpine glaciers conspicuous lateral and terminal moraines remain as evidence of the work done. Such general considerations, as most students of glaciers will admit, no doubt are sufficient in themselves to sustain the demand for ocular evidence as to what has become of the rock removed in case hanging valleys are due to differential ice erosion; but, as I think, a more specific argument in this connection can be presented.

EVIDENCE DERIVED FROM STUDY OF BLOODY AND LUNDY CANYONS

On the southwest border of the basin of Mono lake* there are several deep glaciated canyons, some of which have typical hanging valleys on their sides. Two of these canyons, namely, Bloody canyon and

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*Israel C. Russell: "Quaternary history of Mono valley, California." Eighth Annual Report U. S. Geol. Survey, part i, 1889, pp. 331-333, 337-340.

Lundy canyon, present certain similarities and contrasts which are instructive in the above connection. These two canyons are only about 5 miles apart, are situated on the same side of a mountain range, and hence must have been subjected to the same climatic changes. They have been excavated in rocks of essentially the same degree of resistance to mechanical erosion and were in each instance occupied by a glacier which extended beyond the lower limit of its canyon and entered Mono valley—the Lundy Canyon glacier reaching out half a mile and Bloody Canyon glacier between 3 and 4 miles into the main valley. Bloody canyon has a steep gradient, is about 2 miles long, approximately 2,000 to 2,500 feet deep, and a mile wide at an elevation of 2,000 feet above its bottom. Lundy canyon is 6 to 7 miles long, has a gentle gradient in its lower half, is steep in its upper portion, and about 3,000 feet deep, with a width of approximately 1½ miles at an elevation of 2,000 feet above its bottom. The amount of material removed in order to produce Lundy canyon was certainly five times as great as the similar task in the case of Bloody canyon. If each canyon was excavated by a glacier, it is entirely consistent to conclude that the morainal material deposited by Lundy Canyon glacier should be at least five times as great as the similar material laid down by Bloody Canyon glacier. On the contrary, however, as shown by field observation and an inspection of carefully prepared maps, the recognizable morainal material in Lundy canyon and about its mouth is in volume only a small per cent of the volume of the similar material in and in front of Bloody canyon. The morainal embankments at the mouth of Lundy canyon are simple ridges about half a mile long and between 200 and 300 feet high. The similar embankments at the mouth of Bloody canyon are over 3 miles long, highly compound, and for a distance of over a mile near their source of supply are between 500 and 600 feet higher than the bottom of the trough between them, which itself has a thick accumulation of morainal and stream-deposited material beneath it.

It is thus made clear that the amount of work the Bloody Canyon glacier performed was vastly greater than the work done by Lundy Canyon glacier. Why this discrepany in the case of two neighboring glaciers of approximately the same size and working on essentially the same average character of rock ? The only explanation which seems to fit the case is that Lundy canyon had approximately its present size and shape previous to the origin of the glacier which occupied it, and that the glacier found the canyon, especially in its lower half, so well adapted for its use that but slight alterations were made in its contours, while Bloody Canyon glacier originated where only a comparatively small amount of previous excavation had been done, and it eroded its bed vigorously.

On the south side of Lundy canyon there is a high lateral tributary valley, known as Lake canyon, which is a typical glaciated hanging valley. The floor of Lake canyon is about 1,000 feet above the bottom of the receiving canyon and approximately on a level with the highest evidence of glaciation on its sides. Bloody canyon has recesses in the higher portions of its walls, but none of them can be considered as even moderately well shaped hanging valleys. So far as these two canyons are concerned the one which has undergone the lesser amount of glacial alteration is the one which has the best defined hanging valley opening into it.

Throughout the Sierra Nevada and the Cascade range it is the long, low-grade troughs similar to the lower half of Lundy canyon which have the best defined and most typical hanging valleys opening into them. It is in connection with these canyons, also, that there is a conspicuous absence of evidence, such as is furnished by moraines, of glacial erosion.

CONCLUSIONS

If I have read the story correctly, it would seem that both the destructional and constructional topographic forms due to glaciers in the Pacific Cordilleras of the United States seem to favor two conclusions: First, that the mountains were deeply stream-sculptured before the Glacial epoch, and, second, that certain of the glaciated hanging valleys are not due, either wholly or in a large measure, to differential ice erosion.

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PLUMOSE DIABASE AND PALAGONITE FROM THE HOLYOKE TRAP SHEET*

BY B. K. EMERSON

(Presented before the Society December 30, 1904)

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* This paper is published by permission of the Director of the United States Geological Survey. A friend called my attention to the interesting exposures made in clearing the surface of the trap for a new reservoir, and I asked my assistant, Mr Walter L. Allen, to examine the place. He discovered the interesting plumose trap and the glass described below and collected much of the material for the investigation, and has taken part of the photographs used in the paper. I owe the drawings to the skill of my daughter, Mrs Charlotte E. Hitchcock.

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EXTENT, THICKNESS, AND GENERAL STRUCTURE OF THE TRAP SHEET

The Holyoke trap sheet begins south of Amherst and extends 80 miles across Massachusetts and Connecticut to Long Island sound. It is about 300 feet thick in the latitude of Holyoke and has a low dip eastward, resting conformably in the Triassic sandstones (see plate 24), and plainly was a submarine flow.* It and its neighbors are composed for the most part of a monotonous diabase; but peculiar structures have been locally produced by the introduction in various ways of the mud, sand, and water of the sea bottom into the interior of the liquid and moving mass.

TYPES OF FOREIGN INCLUSIONS IN THE DIABASE

MERIDEN TYPE: BLENDING OF MUD AND LAVA AT THE BASE OF THE BED

I have elsewhere described considerable areas where the trap, protected below by a thin solid crust, has flowed over and rested on the muddy bottom, and then, the crust becoming ruptured and the liquid lava coming in contact with the mud below, many steam explosions have blown fragments of the under crust, with much mud, water, and filaments and tears of the lava, up into the still liquid mass. In one case a pipe-hole was blown clear through the sheet and a mud volcano formed on its surface. By the blending of the cold mud and the liquid lava much basic glass was formed, which differs much from the glass especially described in the present paper (see page 103). By the above process minerals like ægerine-augite and structures simulating those of the crystalline schists have been produced. These basal explosions are not of limited extent. I have described only the fine exposures at Greenfield and Meriden in a paper published in this journal.*

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*See description in geology of Old Hampshire county. Monograph xxix, U. S. Geol. Survey, 1898, p. 446.

TITANS PIER TYPE: BLENDING OF MUD AND SAND WITH THE LAVA AT THE SURFACE OF THE BED

I have also described with some detail another extensive area within which the great Holyoke trap sheet, here about 400 feet thick, is over large patches both at its upper and its under surface contaminated by foreign sedimentary material, which was for the most part marly and is now consolidated into a dove-colored limestone, more rarely into a shale or sandstone. For 10 miles or more along the sheet from Titans pier on the Connecticut to the Holyoke-Westfield railroad (see plate 24) nearly every lower contact shows this contamination for 10 or 12 feet up, and it is present over large portions of the upper surface; almost everywhere indeed where it seemed probable that the exact upper surface was exposed.

The results are very different from the case described above. Everything is in accord with the hypothesis that the great highly heated trap sheet flowing beneath deep water caused ascending and consequent convection currents, by which the adjacent fine-grained marly or muddy sediments were quickly swept over the congealed surface of the trap, and by the disturbance of this thin crust (which disturbances sometimes went so far as to break it up into blocks which careened and sank into the liquid mass) much of the fine mud was quickly mingled with the liquid lava under such pressure that the two were stirred together like two immiscible fluids. This sometimes produced a perfect emulsion, great swarms of drops of the marly mud being carried down into the lava and appearing now as dove-colored spheres of limestone. Sometimes each sphere is white for a small segment at its upper surface which represents the cavity formed by the settling of the mud and which is now filled by the later infiltration of calcite. In these cases the cooling has been so rapid that no augite has formed in the adjacent trap, but all the iron has solidified as magnetite in a fine powder which is greatly concentrated in a band ½ millimeter wide adjacent to the fragments and cavities, thus showing a distinct differentiation. Much more frequently the limestone and the trap are so intricately blended that both must have been entirely fluid at the same time and under such pressure that the moisture could not expand and make the mass scoriaceous. At the other extreme the trap, already solid and porous, has been shattered by small explosions and its angular fragments have been cemented by the mud. Of course all intermediate stages can be observed.

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* Diabase pitchstone and mud enclosures of the Triassic trap of New England. Bull. Geol. Soc. Am., vol. 7, 1898, pp. 59-86, plates 3-9. Geology of Old Hampshire county, 1898, pp. 419-439.

This deposit on the upper surface is repeated on the under surface. That which was deposited on the upper surface was carried forward and downward at the front of the sheet by under-rolling and found its place at last (inverted) beneath the sheet in contact with the subjacent beds. If one compares the base of the trap at the water's edge north of Titans pier, or along the roadway blasted up onto mount Nonotuck above Mount Tom station, with the surface of the trap just south at the great section at Dibbles Crossing on the Westfield-Holyoke railroad, on the south line of Westfield, the identity of the two cases is clear. There may be seen the same blending of the trap with the dove-colored limestone which decreases upward. The mass is very scoriaceous at base, and this decreases upward, with the bubbles inverted. One marked structure appears both in the surface and the basal deposit which furnishes conclusive proof of this inversion by under-rolling, namely, the long tubular steamholes. So much water was carried into the trap that the latter was not only made very scoriaceous, but the steam escaped upward through the trap forming long parallel tubes and keeping them open until the trap was congealed (see plate 25, figure 1, *a*). The same long empty cavities appear inverted at the base of the trap as at Titans piazza running up six inches from the base (see plate 25, figure 1, *b*). The sandstone beneath is soft and unbaked, so that the trap was solid when it reached this position, and it does not seem possible, even if the trap had been liquid, for steam generated in the sand on which it came to rest to bore a great number of parallel holes up into the trap while the layers of the soft sand directly beneath were quite undisturbed. This brings out strongly another important point in which this case is wholly unlike the former one—that is, the Meriden type—namely, the limestone which crowds the lower 12 to 15 feet of the bed can not have been driven up into the trap by explosions from below, because the rock below is a coarse arkose wholly unlike the material in the trap, while in the former case the material carried high up into the trap is of the same kind as that below and is continuous with it, and the bottom scoriaceous layer of the trap is shattered and its fragments are carried with the mud high up into the compact trap. In this second case the lower scoriaceous layer is continuous and grades regularly upward into the compact trap.

The reason for assuming that the fine material was carried out over the trap by rapid convection currents of water is that so large an amount of this material was spread on the sheet during the short time of the outflowing and underrolling of the lava and before it came to rest, while the material deposited on it after it came to rest was much coarser. It is perhaps possible that the fine mud was spread over the trap by the ordinary process of sedimentation, because of an exceedingly slow advance of the mass, but this would seem to involve a sufficient thickness of the crust to prevent the blending of this mud with the still liquid trap beneath.

Unlike the first case, this process has in the cases previously described produced no glass and no metamorphic effect. We may call this the Titans Pier type. The mud has been mingled with the lava superficially in great quantity at the lowest possible temperature and pressure, and the heat has acted for the shortest time. This explains the difference in the results between this and the Meriden type.

HOLYOKE RESERVOIR TYPE: BLENDING OF MUD AND LAVA IN THE CENTRAL PORTION OF THE SHEET

General statement.—In the case now to be described the mud which in the immediate vicinity is spread over the surface of the trap seems to have been also drawn down more than a hundred feet into the interior of the mass, and thus, while subjected to increased pressure, time, and heat, to have produced physical and chemical changes as intense but very different from those of the Meriden type.

Description of the area.—The map (see plate 24 and section) shows a portion of the main trap sheet 5½ miles long. At the south end, in the extreme southwest corner of Holyoke, at Dibbles Crossing, is shown the superficial area of the trap, which is filled with inclosures of drab limestone and shale, after the Titans Pier type. South of the Dibble house the railroad cut shows the structure perfectly. In the ridge just southeast and also in the brook cutting beneath the next house south * the sandstones can be seen resting on the diabase-limestone emulsion and the exposures are entirely satisfactory. A half mile northwest, out on the back of the deeply eroded trap ridge, is the area in question of the Holyoke reservoir type. It is about 1 mile long and 40 rods wide in its southern part. Topographically it is a quite deep depression in the trap, more so than the contour lines indicate, and was naturally chosen for a reservoir. North of the road the depression is continued across swampy and covered ground a mile farther north, where it becomes a deep notch in the trap in which the glass-bearing rocks of the reservoir again occur and have been blasted into for the electric road.

The section shows that the area is about 150 feet below the upper surface of the trap sheet, though the possibility of faulting is not excluded.

The normal diabase.—The trap in all this portion of the great sheet is the typical dark and fine grained Holyoke diabase. It is exceptionally fresh and compact, but is everywhere cut within the given area by schlieren or segregations of peculiar coarse-grained diabase types.

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*See figure 1 in "Diabase pitchstone," etc. Loc. cit., p. 62.

Résumé of the structure of the abnormal area.—Down the middle of the abnormal area runs a narrow band which contains rather sparingly fragments and filaments of a light pearl-gray clayey limestone exactly like much that is found in the upper surface of the sheet. The introduction of this mud caused much of the magma to crystallize in a coarse gabbroid diabase, greatly shattered the mass and seamed it with many quartz-ankerite veins. The fine trap on either side of this band is full of "schlieren" of the strange, coarse, gabbro-like varieties, which will be described in detail. In them the pyroxene shoots out into branching and curving feathery plumes several inches long, with central suture and transverse parting, which heightens the resemblance to a feather; or the feldspars occur in broad plates nearly an inch square, poikilitic with abundant pyroxene and palagonite grains in beautiful plumose arrangement; or the whole is crowded full of clots of black palagonite, which include spherulites of calcite and radiate blue quartz, and these glass clots are surrounded by broad acid, almost purely albitic, areas. Finally, and this seems of first importance for the explanation of the strange development, the coarse schlieren, which taper to nothing in the fine trap, have often a narrow central band of whitish aphanitic and very acid diabase, containing little or no pyroxene, of the same type as that surrounding the glass. This type may be associated with the white diabase which I have elsewhere described as "holyokeite."*

Abstract of theory of formation of plumose forms and of palagonite.—We can perhaps describe the multitude of exceptional and contradictory forms and phenomena crowded together here more lucidly and not less objectively if we arrange them in accord with the theory which seems best to bind them together and which we may state baldly as follows:

(1) Along a narrow band parallel with the front of the sheet a great volume of the mud, like that found on the surface, was drawn down a hundred feet or more into the interior or the molten trap sheet by irregular vortex motions of the flowing mass.

(2) Under the high temperature and pressure the quartz and carbonates of the mud were abundantly dissolved. Strong internal motions carried sheets and filaments of the magma loaded with these solutions out into the adjacent area as great schlieren. A central band contains the remnants of mud which were not dissolved and carried out into the magma by convection or diffusion, and here explosions of the muddy water have shattered the newly solidified rock, and the calcite and quartz solutions have cemented it into a central breccia. The normal trap on either side is full of coarse schlieren, which represent the streaks

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* Holyokeite, a purely feldspathic diabase from the Trias of Massachusetts. Jour. Geol., vol. x, 1902, p. 508.

of the magma loaded with the dissolved material drawn out into it. The superheated water and dissolved salts acted as "mineralizers" in a general way to produce the glass with spherulites, the plumose pyroxene, the coarse pegmatitic or poikilitic plagioclase, the large skeletonized magnetites, the micropegmatitic albite, and all the indications of rapid and abnormal crystallization and resorption. A remarkable differentiation has taken place in interstitial remnants of the magma into (1) a dark, much hydrated, glass (palagonite), in which beautiful calcite spherulites and sphærocrystals of ankerite and blue quartz have formed, and (2) an acid quartz-albite ground, which surrounds the palagonite, and has also been extravasated in small dikes, which I have called holyokeite.

DETAILED DESCRIPTIONS

CENTRAL EXPLOSION BRECCIA

The trap sheet is seen on the west to rest on a coarse buff sandstone or conglomerate, and there is no indication that any material has been carried up from below. It is thus not probable that this is a case coming under the Meriden type. On the contrary, at the nearest outcrops of the surface of the sheet areas of many acres are full of an indurated mud of exactly the same texture and color as that found here in the center of the sheet. It is therefore probable that the reservoir type is a downward extension of the Titans Pier type. Furthermore, the fragments of sandstone found in the breccia are sometimes perfectly stratified, showing that they had been sufficiently indurated at the surface to be transported into the mass without being wholly broken up, and this is also the case with the mud inclosures at the surface. Further, this included sandstone contains many scales of graphite, which is a widely disseminated constituent in the Triassic sandstones, making it certain that they have a common derivation. Moreover, the abundant fracturing and the cementation are confined to the central band, where the fissuring is an original structure, and not one due to the upturning of the rocks, since large blocks of the trap were broken open in the blasting and isolated fissures found within them.

The paragenesis of the pearl-gray vein fillings of these fissures is exceedingly interesting for our purpose. On either wall of every fissure is a layer of a ferruginous carbonate, probably an ankerite.* Within these rusty carbonate layers are quartz layers, generally granular, but sometimes in perfect limpid crystals, one-third of an inch across, which are at times amethystine. A third layer is a calcite in scalenohedra, R^3, sometimes terminated by $-\frac{1}{2}R$, or in cleavable masses coating the other crystals or filling the cavity, with here and there a rich oil-green lustrous grain of apatite completing the filling. These veins are thought to have been formed immediately after solidification. It is interesting that there is no trace of datolite or zeolites in these veins, as both are abundant a few miles south and generally in the trap. They seem to occur only where large faults go through the trap dikes. In the north part of the reservoir area larger fragments of a gray flat-bedded calcareous sandstone occur, included in the shattered trap, with many mica scales on the laminæ and many scales of graphite imbedded. These sandstone fragments are quite large, and, in contrast to the small and rare fragments of the marly sandstone in the breccia farther south, they contain, indicating the violence of the explosions, small fragments about an inch across of the same coarse weathered gabbroid diabase. These occur just south of the sharp bend in the road between Hitchcock pond and Rock valley. The rock of the breccia varies in coarseness rapidly. The stout plagioclase blades are often 8 to 10 millimeters long and are opaque white because they are uniformly changed to mats of coarse tufts of a white mica like the plumose muscovite of granite. This I take to be an original structure, produced by the continued activity of the heated waters and not a late product of subaerial influence, since it is uniform in the center of great blocks newly blasted out. It is metamorphism and not weathering. The ferromagnesian constituent is often changed to a deep green chlorite. The immediate influence of the abundant water is thus very strong, and is different from what it is in the schlieren rocks. All the minute mud fragments are surrounded by a broad band of crystalline quartz and calcite, showing that they have all shrunk and given up much water to the trap.

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*This is, under the microscope, often made up of perfect rhombohedra with convex faces, which are limonite-dusted in concentric bands. In basal and vertical sections of each rhombohedron there appears a perfect large black cross. The curved-face form is in effect a composite with many radiating axes. This produces the same result as a radiate-fibrous structure.

OCCURRENCE OF ANALCITE

In the small steam holes in a block of altered gabbro, near the center containing holyokeite dikes, the cavities are filled with a colorless nonpolarizing mineral with cubical cleavage, whose index of refraction is below the balsam. This is doubtless analcite.

GENERAL DESCRIPTION OF THE SCHLIEREN

The schlieren appear in irregular bands or sheets from a fraction of an inch to several feet in the smallest dimension and tapering off to a thin edge in the midst of the fine-grained trap. Where these bands come in contact with the fine-grained trap the transition was not marked by a fissure as if one while hot had been injected in the other after its solidification, yet this transition was often very abrupt and was always made within an inch. The coarse variety generally seemed like "schlieren" in the finer, but also seemed at other places to have been fluid for a slightly longer time, since small dike-like apophyses two or three inches wide branched off from the coarser and penetrated the finer rock for several feet, and fragments of the finer rock were sometimes slightly separated from the rest and floated off into the coarser. The long blades of the augite often rest by one end on the surface of the finer trap and project into the coarser for an inch or more. It was as if some foreign fluid had been introduced into the liquid lava when near solidification, and had been stirred into it in irregular streaks by the internal motion of the mass, which fluid made that part of the trap a little more easily fusible, so that it remained liquid for a slightly longer time than the rest and crystallized into coarser and peculiar types. There was thus a transition from the schlieren to the dike condition. It was repeatedly observed that several of these schlieren were placed one above another and all about parallel with the upper surface of the trap sheet, as if their shape was controlled by the advancing motion of the main trap sheet.

VARIETIES OF THE SCHLIEREN ROCKS

Long plumose diabase.—One of the most remarkable of the schlieren rocks, which I have called the long-plumose diabase, is found only in the immediate vicinity of the breccia band, and contains filaments of the brightly rusting ankerite derived therefrom. It is a coarse grained, jet black, fresh looking rock, in which the feather-like pyroxenes have shot out in flat, thin blades 3 or 4 inches long and nearly a fourth of an inch wide (see plate 26 and plate 27, figure 1), which radiate in plumes like a radiated actinolite. They branch at small angles and are bent gracefully or sharply twisted, as if they had shot out rapidly into the liquid glass and had been swayed in its currents like a tuft of grass leaves in the wind. A twinning plane runs down the center of each blade, and close set basal partings run at right angles to the same. These have the effect of the midrib and pinnulæ of a feather. The resemblance to grass is greatly heightened because the rock has been fissured across this band, and many of the pyroxenes have from weathering turned a bright green, or even straw color and white like dry grass. This is a change to talc. This variety appears in perfection only in a narrow, irregular band about 10 inches wide, traceable several feet in the ledge near the band of sandstone inclusions. This growth is essentially spherulitic, although the sheaves form only a small portion of a sphere.

There is a resemblance to the curved and branching feldspar blades in the spherulites of Obsidian cliff. Professor Iddings cites Lehmann's explanation of unequal surface tension for the curved forms.

The pyroxene is an almost colorless sahlite, which is slightly blackened by refusion at surface and along certain cleavage planes, and this causes the black color. The basal parting is very marked, and this causes the feathery appearance. The central section is caused by twinning according to the usual law on (100), and the crystal is uniformly flattened on two of the prism faces (110), so that the twinning plane passes obliquely through the thin plate, causing the broad central suture, which completes the resemblance to a feather. The extinction is therefore about 23 degrees obliquely to right and left, and an optical axis appears in the border of the field. The photograph (see plate 26) shows imperfectly the length and curved character of the blades, which are frequently notched along their sides by faces of the unit form. The figure (plate 27, figure 1) shows much better the feather-like texture. The associated feldspar is labradorite ($ab^3\ an^4$), with extinction 30 degrees on (100).

This variety, because of its proximity to the breccia band, has, like it, its feldspars sometimes almost completely changed to a radiate tufted mica, probably paragonite, whose fibers are arranged in its cleavages. They are optically positive. Its pyroxenes are loaded with black granules along the parting planes.

There is no glass in the brecciated band, and here glass particles are rare and completely altered. They are often minute, hollow, and beautifully botryoidal lithophysæ, and the cavities are lined with a coarse radiating, brightly polarizing devitrification product, which is sometimes coated by a layer of secondary calcite.

Short plumose variety with remelted pyroxenes.—Another striking variant, which may be called the short plumose form, is very fresh in appearance, jet black, and coarse grained, and the abundant pyroxenes are in short blades, twinned like those described above, but only about an inch long. The peculiarity of this type of the trap is that all the large pyroxenes are more or less remelted while retaining, wholly or partly, their original positions and traces of original structure. This is shown in plate 27, figure 2. The common pale brown pyroxene (see *h* in the right central portion of the figure) has the strong prismatic cleavage (horizontal in the figure) and a trace of the nearly vertical basal parting. Below this a broad dark band *g* runs down athwart the figure; flanked on either side by a lighter brown band *dg*. These are glass from the melting of the pyroxene. In the zone of transition between the glass and the pyroxene the basal parting is developed into an almost micaceous cleavage, and this and the prismatic cleavage can be traced through the whole glass. The central part is mostly non-polarizing, but small unchanged patches still polarize like the pyroxene above. The border of lighter color is a devitrified, less ferruginous glass, and polarizes independently. This is seen to run out in a delicate fringe of glass filaments into the colorless ground, and this fringe is more or less filled with grains of magnetite, as in a common resorption rim. Outside this is a narrow band of the quartz-plagioclase ground, full of long feldspar microlites in fluidal arrangement. This is surrounded by a broad band of original calcite, partly in broad well cleaved untwinned grains, partly of grains made up of a matted fibrous mass, as if changed to aragonite. This contains several clots of the brown fibrous devitrified glass, and is outwardly interlaced with the coarse feldspar and pyroxene crystals. This variety lies next outside the long plumose variety, where the strong currents swept the suddenly formed blades out into a hotter part of the magma and the partial remelting occurred, with the formation of a glass blacker and still more ferruginous than the normal palagonite described below.

The type contains many large glass masses in which secondary alteration has developed many structures which are concealed in the fresher types. Their description is therefore deferred until after that of the simpler varieties (see page 118).

Glass-bearing porphyritic diabase.—This is the most interesting variety of the trap. All the best specimens came from a great block near the south end of the reservoir clearing, but all the peculiarities were found on both sides of the central bands described above in the great schlieren everywhere, but not all concentrated so abundantly in single hand specimens. I do not think any one familiar with the Holyoke trap would think for a moment that the rock could come from that sheet. The black, perfectly fresh surface, with strong greasy luster, that suggest an ultrabasic rock rather than an exceptionally quartzose one, the large and abundant porphyritic and poikilitic feldspars, inconspicuous only because of their perfect freshness and limpidity, and the abundant clots of jet black glass with their spherulites and inclosures of calcite crystals and sphærocrystals of ankerite and blue quartz, form a strong contrast to the monotonous Holyoke diabase. The large porphyritic feldspars are often almost an inch square. They are so fresh, glassy, and transparent that they are little distinguished from the mass of the rock. They have straight triclinic striation produced by twinning according to several laws, which is often wanting over large areas and very unequally spaced. One large crystal cut on (001) extinguished at 12 degrees, indicating labradorite. They are poikilitic, with many rounded or elongate inclusions of the dull black pyroxene and of glass and spherulites.

These inclusions become elongate and lobate and produce a kind of micropegmatitic structure, or are in bands parallel to the outer boundaries, or beautifully plumose, completely filling and skeletonizing the crystal (see plate 27, figure 3, lower part). The crystals are squarish, but often send out long lobes, as if formed very rapidly, and indeed a rapid growth is indicated by the abundant inclusions. They are often in large crossed forms like the cross-section of a staurolite or double arrow-head twin of gypsum (see plate 28, figure 6).

The pyroxene is often very inconspicuous, and over considerable areas is found wholly in poikilitic arrangement inside the feldspars. Rarely a long twinned blade connects this type with the short plumose variety. Many large sections are almost wholly made up of cross-sections of the large fresh feldspars crowded full of these inclusions, often in beautiful dendritic arrangement and on so large a scale that it can be studied with a lens. The magnetite is also in unusual forms—in large perfect octahedra, the faces marked by strong cleavage lines or beautifully skeletonized with inclosures of the colorless ground or of glass. When, at the surface of blocks etched by the marsh waters, the inclusions have been removed, and the magnetite rusted to a rutile color while retaining its brilliant luster, it looks like a sagenitic network of three dimensions (see plate 27, figure 3).

A surface from the large and best glass-bearing mass is covered by a fine striated slickensides made up of dark green antigorite with its prisms set at slight angle to the surface. The color of the mineral in a slide is green to brown. It is optically negative, with small optical angle.*

Gabbroid diabase.—This most abundant variety of diabase in the schlieren is so coarse that all the constituents are visible to the eye. It is often entirely fresh, so that the lathe-shaped feldspar is wholly transparent, and the coal black color is given by the magnetite and black pyroxene. The magnetite is often in large, sharp octahedra with striated faces. The pyroxene is in short blades, showing the beginning of the feathery form described above. Glass appears in small spots, hard to detect because of the freshness and dark color of the rock, and this glass appears even where the grain sinks to the fineness of the common trap. Only the granular calcite and the deep blue quartz appear prominently in this variety. Here alone the glass has opaque, black central portions from the great amount of the iron. This variety is especially abundant in the great schlieren along the electric railroad. It may grow even coarser and the pyroxene occur in blades an inch long with the feather-like character described above, but it does not then contain the glass in great quantity. It occurs also, but without glass (though much that we have called delessite may be devitrified glass), far north of the locality we are describing, at the surface of the ledge at Titans pier, on the Connecticut river. This type often forms also a transition to the last, in that the pyroxenes are often partly melted. A central unaltered nucleus is surrounded by a broad band of granular recrystallized pyroxene. Outside this is sometimes a partial band of a deep green chloritic mineral, and outside this a broad area of dark glass, doubtless derived from the entire melting of much of the pyroxene. In other cases the nucleus is surrounded by a very broad black resorption band, largely made up of granular magnetite.

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*In the Massachusetts state collection no. xvi is a specimen of the coarse porphyritic trap with long plumose pyroxenes, which manifestly came from the reservoir region. It contains many quartz inclosures and cavities with dog-tooth spar crystals. The specimen is labeled "Greenstone passing into syenite (boulder), West Springfield."

These last varieties are generally perfectly fresh and are located far out on either side of the central band of impurities, and yet a trace of the bluish quartz appears here to show that the mineralizing fluid was carried to the outer border, but did not act to produce decomposition of the minerals formed. It promoted a widespread differentiation of the magma into a very hydrous glass, which, calculated in the anhydrous state, is more than a third iron. As the magnesia went with the iron into the glass the acid differentiate had almost the composition of an albite. We have thus to discuss (1) the basic glass or palagonite, (2) the spherulitic inclosures in it, and (3) the acid halo surrounding the glass and forming a felsitic ground in all the coarser varieties, and also appearing as small aphanitic dikes.

DESCRIPTION OF THE PALAGONITE

The glass is in irregular portions, the longer from 1 to 30 millimeters in length, occurring often 20 to 30 in a square inch, and with a lens and the microscope many more swarms of minute patches and globules of the red brown glass appear. They are lobate and have formed in place. They are generally velvet black with highest glassy to resinous luster, more like common asphaltum than like obsidian. At times the larger grains are centrally of a slightly lighter shade of color, or two shades are concentrically interbanded as in agate. It is very soft and brittle; its hardness is 3, and its specific gravity is 1.91. It is deep red brown by transmitted light with brownish white streak. It is red brown in thin-section, and sometimes a central portion is so deep colored as to be opaque. It is very rapidly dissolved in weak cold hydrochloric acid, and when a piece of the rock is put in strong acid all the grains of the glass soon show a cracked surface and a golden brown color like a dark resin; but the acid soon dissolves all the iron and leaves behind a white curd-like mass of silica which fills with cracks like drying starch. Often-times the whole interior of the grain except a thin exterior film, which remains jet black, changes into a dull opaque greenish black amorphous mass. Its hardness is then 2.5–3 with the streak light green. The contrast between the thin continuous border of the velvet black glass and the dull greenish black slightly fibrous mass is marked and the transition line is sharp.* The shining black glass border is wholly non-polarizing. The dull black center shows in thin-section a shade of green and polarizes very dimly in several broad concentric bands. Each band is opaque at its outer edge and gradually lightens up more and more to the inner edge. The bands are faintly fibrous. When treated with acid the black exterior unaltered glass becomes crackled, and because of internal reflections looks brown, but soon changes into a white-fissured mass, while the weathered interior changes first to a light green and then more slowly than the border becomes opaque white, but almost without cracking. It melts into a scoria with the blowpipe.

There is probably a slight chemical difference between the first formed central portion of the glass and the exterior, in virtue of which the former is less stable, and it is possible that iron is more protoxide in the green interior and more peroxide in the brown exterior.

This glass is entirely different from that found at Meriden and Greenfield mentioned above. That occurs in large masses, with isolated microscopic crystals of feldspar and augite, and its spherulites are microscopic drops of glass made up of concentric layers and mingled in the confused breccia and beautifully devitrified. It is very hard, not affected by acids or alkalies, and is a liver-colored basic pitchstone, resembling the tachylite of Ostheim, in Hessen. It decomposes very slowly under weathering. This glass, on the contrary, is very soft and brittle, very easily dissolved by acid and slowly by caustic soda, and decomposes very easily into brown greasy masses, and is quickly removed from the cavities near the weathered surfaces. It is thus quite exactly like the palagonite of von Waltershausen, and I have used this name to distinguish it from the normal tachylite from Meriden.

BOTRYOIDAL GLASS WITH RADIATE FIBROUS DEVITRIFIED LAYERS

In the short plumose diabase, with remelted feldspars (see page 100), the glass is more complex. Many large glass masses occur, which are generally centrally altered to a dull greenish black mass, with a thin rim of the unaltered fresh glass remaining. These glass clots are often beautifully botryoidal and show agate-like color banding in shades of black (see plate 30). The botryoidal cavities are sometimes empty or have a filling of calcite or blue quartz. Figure 2 on plate 30 shows such a botryoidal cavity, where, within the thickness of the glass itself, is a distinct spherulite in which the few concentric bands are marked by a darker parting and by a few original calcite crystals. The spherulite and adjacent glass are wholly non-polarizing, but grade into a portion not visible in the slide which is beautifully banded like an agate in a few broad layers, concentric with the botryoidal interior and faintly fibrous and in this state polarizing distinctly but weakly. It is lined by a very regular double band of a lighter and completely fibrous substance in slightly radiated tufts, often raveled out inwardly and polarizing more brilliantly than the banded glass. The fibers in both varieties of glass are positive and give a perfect coarse black cross. This brightly polarizing inner band may be thought to be an immediate alteration of the glass for a certain distance inward, produced by the absorption, before the deposition of the quartz, of the H_2O whose expansion caused the cavity. This is possible because both in this rock and the long plumose variety the magnetite, which was the earliest to crystallize and which in fresh pieces incloses clots of glass, here incloses particles of the same size and shape of the green fibrous, brightly polarizing substance.* This lighter double band lines the cavity perfectly in all its windings to near one end, where it stops suddenly as if ruptured, and the remaining wall of the cavity is of the darker glass, but fractured and irregular. Where the section cuts the globular projections it shows the black cross beautifully. Outside is a broad layer of the microlitic quartz-albite ground which I have below described as holyokeite. The whole is inclosed in the angular space between several of the large feldspar and pyroxene crystals, and is an isolated portion of that which makes up the whole ground of the rock in the porphyritic variety above described (see page 101) and in the holyokeite dikes.

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* The dull glass appears in the fresh coarse rock at the big schlieren on the electric railroad and in the central portion of the glass-bearing diabase at the reservoir.

SPHERULITES, SPHÆROCRYSTALS, AND LITHOPHYSÆ IN THE GLASS

The glass may inclose (1) small perfect crystals or (2) crystal groups and sphærocrystals of calcite, or (3) of calcite and ankerite, or (4) beautiful spherulites with alternating layers of calcite and the black glass, or (5) small masses of fine granular pale blue quartz, or (6) sphærocrystals of richest cobalt blue quartz, fibrous and eccentrically radiate, or (7) any combination of the above forms (see plates 28 and 29, with descriptions). The glass many times molds perfectly the minute crystal ends of the calcite and the quartz and always incloses them entirely, and there can be no doubt that they have crystallized out from the liquid magma in quick succession, and the calcite has always crystallized first. The presence of calcite and quartz in solution together in the magma perhaps presents difficulties. It can only be said that the proof of the fact seems complete, and that at a pressure which would prevent the breaking up of the $CaCo_3$ molecule, it and quartz may well coexist.

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* Several delessites and chloropals occurring in basalts have a composition very close to that of the glass. Much may be said in favor of the opinion that the so-called diabantite or delessite in the Triassic traps hereabout may be in large part altered palagonite. The diabantite always appears in the weathered rock just where the palagonite would be devitrified. On the other hand, the trap when as much or even more altered often fails to show a trace of the diabantite, which may be thought to be because the trap when fresh did not contain palagonite. The cavities in the Icelandic palagonites are also always lined by a fibrous layer which polarizes brightly (see Page 122).

The glass also contains minute lithophysæ with crumpled inner surfaces often filled with sphærocrystals of ankerite and quartz. All the forms enumerated in this section are described in some detail, in connection with the theoretical discussion as to their origin, on pages 117.

THE LITHOIDAL OR HOLYOKEITE BASE

There appears around the glass clots or groups of clots a broad bluish halo of very fine grained base, which seems at times purely quartzose or chalcedonic—at times felsitic—always compact and aphanitic. It is sometimes clear blue, but more often bluish black to black. The larger phenocrysts are often excluded from this halo for a considerable space.

This base is found with the microscope to be extensively developed as a kind of mesostasis in small isolated angular patches in the plumose and coarse ophitic types, and making up the whole ground in the coarse porphyritic quartz diabase included in and between the great feathery feldspars. It is an interesting case of micro-differentiation.

Where the interstitial areas are bounded by feldspars the glass clots tend to be central. Where the boundary is partly pyroxene the glass is apt to be adjacent to it, as if a differentiation had set up in the original interstitial magma (caused by an influence of the already formed feldspar surfaces like that which causes albite to coat the surface of microcline), by which the albite-quartz hyalopilitic ground grew outwardly from the feldspars, rejecting and crowding away the black basic iron-magnesium glass. Under the microscope it is a colorless base or is pale brown from a great quantity of brown dust, sometimes aggregated in fusiform shapes. With polarized light a beautiful and peculiar hyalopilitic structure appears (see plate 30, figures 3 and 4). The delicate satiny needles of plagioclase radiate from central angular or shapeless albite grains, and are often arranged in very beautiful and characteristic loose anastomosing groups like hoar frost, the interspaces being filled with a mosaic of shapeless and blending grains. With common light these grains are indistinctly fine fibrous; with polarized light they seem to be albite filled with minute quartz rods, forming an exceedingly fine and close set micropegmatitic structure. This ground passes into radiate-fibrous forms, showing abundant black crosses and the purity and bright polarization in whites and grays which characterize water-deposited quartz. The fibers are always positive, so that quartz and albite are hard to distinguish. It is generally full of small clots or beads of glass, forming an exceedingly fine brown dust. Sometimes the minute straight plagioclase microlites show a fluidal arrangement; sometimes many large and long crystals of apatite* and large square prisms of plagioclase occur quite abundantly, the latter with a central thread of glass like a minute chiastolite (see plate 30, figures 3 and 4). There are often many small irregular patches of calcite grains. It seems to be only when the glass is especially abundant that the aphanitic halo which surrounds it shows an excess of silica by the blue color and effervescence with soda. Generally there is only excess of silica enough to produce the micropegmatitic structure. When such a bluish piece of the lithoidal rock is boiled for several hours in caustic soda a very considerable portion is dissolved, and the few feldspars stand out in relief, and an unexpectedly large number of minute pyrite cubes appear. The glass is, of course, also deeply dissolved and the remnant is cracked and brown. When a fragment is fused with soda it effervesces abundantly and is mostly dissolved.

THE HOLYOKEITE OR DIABASE-APLITE DIKES

We pass by an easy transition from the isolated halos of the quartz-albite mixture which surround the glass and forms the groundmass of the coarsest gabbros described above to the small tertiary dikes of an aphanitic trap of light color which prove to be identical in character with the above groundmass (see plate 30, figures 3 and 4) and approach holyokeite so closely in composition that it will be convenient to apply the same name to both. They cut both the normal diabase and the secondary coarse schlieren of glass-bearing diabase and in many cases run down the middle of the coarse schlieren for long distances (see plate 25, figure 2).

Under the microscope the dike material shows so many affinities to the glass-bearing quartz-diabase schlieren that the idea that they are more acid differentiates from the latter is strongly suggested. There is the same abundance of yellow glass, here always devitrified, into which long stout needles of plagioclase have penetrated, and the holyokeite ground is identical in both (see plate 30, figure 4). Calcite in small shapeless masses is often blended in the mass, and the fresh state of all the constituents favors the conclusion that they were introduced together from without and are not products of decomposition. There is also very little magnetite, much pyrite, very little pyroxene, the latter in long isolated and uncorroded blades. The latter characters ally the rock more with holyokeite. The brown-dusted hyalopilitic ground is also indicative of the same alliance, but the rock is generally distinctly different from the first described holyokeite, though sometimes almost grading into it and very peculiar. While the normal holyokeite has the usual ophitic ground like the common diabase with the ferruginous constituents (except pyrite) absent, this is a peculiar variant of the hyalopilitic ground. It simulates a ganglionic structure. Central feldspathic areas—sometimes regular phenocrysts, sometimes irregular angular areas—send out abundant shining white needles which sometimes branch or seemingly anastomose into pretty tufts like frost flowers, and the interspaces are filled by micropegmatitic albite. There is also a remarkably complete although irregular blending of this cryptocrystalline ground with fibrous quartz, so that sometimes minute black crosses, indicative of the latter, can be seen everywhere in the field. The blue fibrous quartz thus associates most curiously on the one side with the feldspathic ground and on the other with the glass. In one slide many perfect quartz crystals just visible with the lens were scattered porphyritically in this groundmass.

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* The apatites crystallizing in the albitic ground surrounding the glass would seem to add one more case to the short list of exceptions to the rule that the apatite crystallizes first. The later appearance is a proof of the rapid formation of the large poikilitic feldspars.

The rock has thus affinities in several directions. It is plainly a trap in its prevailing characteristics, and is a differential from the main quartz diabase in the direction of the holyokeite, and a slightly greater abstraction of iron would have made it a purely feldspathic trap like the original holyokeite. I have no doubt that this is the explanation of the latter rock. We may call the present case a quartz and glass-bearing holyokeite.

On the other hand, the chalcedonic quartz is often deposited so abundantly in the mass that it forms a transition to the quartz-calcite veinstones to be described in the next section but one.

Indeed, I do not know of a more perfect instance of a transition from a purely igneous through igneoaqueous to purely aqueous solution than is here presented.*

A COMPOSITE DIKE

On plate 31 is shown a peculiar composite dike about four inches wide, which is exposed for several feet in the ledge. This dike is about four inches thick, and is a composite of basic diabase aphanite, coarse plumose diabase, holyokeite, and quartz, and occurs near the center of the abnormal band. The larger piece is deeply weathered, so that the two lighter bands stand out a half inch on the surface. The smaller piece shows a fresh fracture, and the central finer grained band is identical with the left band in the piece below. If it had been pushed a half inch more to the right the coincidence would have been more apparent. Starting at the right of the large block, the first portion (*a*) is the fine-grained diabase forming the ledge, presenting a weathered, uncharacteristic surface. Next, a narrow vein of quartz (*b*) projects strongly. Third is a band of a fine-grained black diabase (*c*). Fourth, a broader band of the coarse, long-plumose diabase (*d*) which appears also on the upper fragment. Next is a band of the fine grained holyokeite (*e*), which bends over from left to right in the larger block, and is deeply etched and bleached, so that its outline does not show as clearly as it does through the center of the upper block. Lastly, a narrow band of the "country rock," the fine-grained diabase (*a*), appears in the lower rock and makes the left hand half of the upper one. This has a coarser texture just adjacent to the holyokeite (*e*) and grades into the common ground. This is a light gray rock, more granular than ophitic in texture.

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* Holyokeite is also found at Greenfield as a cement of the glass and sand fragments which have been carried up into the sheet by explosions from below, and is there also a differential result of the action of the water on the normal diabase.

The difficulty of explaining this occurrence arises from the fact that apparently conclusive evidence is present to show that both the coarse diabase and the holyokeite must have solidified first. The inch wide holyokeite dike (*e*) was exposed for 7 feet, with constant characteristics, and it would seem that the diabase must have solidified and cracked to make a place for it.

On the other hand, the coarse diabase has begun to crystallize on the opposite surfaces of the holyokeite dike, and its great crystals bristle out from it and diminish in size gradually as the coarse passes into the fine diabase, and it would seem that the surface of the solid holyokeite must have been there first.

One may assume that the holyokeite was the result of a differentiation which took place in an adjacent area, and that, having the composition of albite, it would be highly viscid and would solidify at a higher temperature than the basic and highly ferruginous diabase.

It is perhaps possible, but only remotely probable, that the holyokeite was carried by the violent motions as a broad, thin sheet of liquid material (a schlieren) into the still liquid diabase while so viscid as not to mingle with it, and then cooling first furnished the surface from which the large pyroxene and feldspar blades shot out, forming the coarse diabase. The even thickness of the half-inch layer over at least two yards militates against this.

Again, it is perhaps conceivable that the diabase just become solid may have been cracked by the many explosions, and the adjacent holyokeite, still liquid and thus at a much higher temperature than the barely solid diabase, may have filled the fissure and have imparted heat enough to the walls to cause a refusion and coarser crystallization adjacent to itself.

A further difficulty arises from the fact that while the slightly coarser diabase on one side of the holyokeite (*e*) grades outwardly into the normal diabase (*a*), on the other the coarsest plumose texture is continued for 3 inches and abuts against the black diabase (*c*) without transition, the great needles rising from the surface of the black diabase as from the surface of the holyokeite.

The surface of contact on the black diabase (*c*) is a plane from which the great crystals spring, making the impression strongly that it was a solid surface when they were implanted on it. On the other hand, on contact with the holyokeite (*e*) the blades spring from the surface of the latter commonly, but sometimes penetrate the holyokeite as if the two had been plastic together.

The thin band of black diabase seems to be excessively rich in iron and to be the correlative differentiate of the white acid holyokeite, and how this comes to occupy its present position and to be separated from the country rock by a thin vein of quartz, which sends branches into the black rock, is hard to see.

The preceding partial and tentative explanations may be taken rather as expositions tending to make clear the great complexity of the curious dike. The hypothesis that best correlates the facts would be as follows: The newly solidified trap (*a*) was fissured and the black extra basic trap (*b*), made basic by a slight differentiation in an immediately adjacent portion of the magma, was injected and solidified. A later explosion reopened the fissure along its left-hand wall three inches wide and the magma filled it. The surface of the highly pyroxenic diabase (*c*) stimulated the growth of the pyroxenes in this magma, and they shot out nearly across the cavity, forming the long-plumose diabase (*d*) and thrusting, as it were, the more acid portion of the magma across to the opposite wall, where it solidified as the holyokeite. The definiteness of the plane between *c* and *d* agrees well with this, and the good degree of definiteness of the other boundary with exceptional blades of pyroxene penetrating the holyokeite (*e*) would also comport well with this description. The slight increase of texture of *a*, immediately adjacent to *e*, may be due to the reheating from the introduction of the new magma.

The quartz (*b*) is an abundant last intrusion everywhere, and a last explosion may have reopened the fissure on the other side of *c* and permitted its entrance.

This seems to harmonize with the explanation elsewhere advanced in this paper to explain the appearance of the holyokeite ground sporadically in the coarse diabase, namely, abnormal conditions stimulate the overabundant growth of the pyroxene and magnetite, and the albitic magma remains as a sort of *caput mortuum* and crystallizes where it can find place either interstitially or squeezed out in small dikes.

QUATERNARY VEINS OF QUARTZ, OF CALCITE, AND OF TUFF

Small veins of quartz and calcite cut all the three types of diabase described above. They contain at the border much pyrite and a little calcite and are often distinctly bluish.

Other similar veins are so loaded with the finest dust of the trap that they may be called tuff veins. In the midst of the coarse trap occur these apparent dikes of fine-grained trap, which prove to be made up of fine dust of the coarse trap of the type in which much of the diabase has been remelted. A slide was cut from a half-inch vein. This is bordered on each side by a band of the radiate granular quartz. This band is doubled on one side as if after the fissure had been injected full of the fine mud produced by the friction of the walls of the trap on each other the superheated waters had cemented the whole with quartz and then the cavity had widened, so as to separate the solidified mud from the walls (or the mud shrank on solidifying), and the narrow space on either side had filled with the pure quartz, and the fissure widening again on on one side a second comb of quartz had come in to fill the second cavity.

The contents of this vein are curiously obliquely banded as if the crack had had a dip of 20 degrees, and layers of coarse and of fine stuff had been dusted in so as to lie horizontally. Others are full of finer dust and grains of the granular quartz and calcite cement. There is always a thin band of pure radiate quartz, separating each fragment of trap from the common ground, and there are also minute veins of pure dolomite or ankerite separating these tuff veins from the adjacent trap.

The amount of the ferruginous carbonate is so great that the veins are always brown on the surface. This allies them with the many coarser veins in the central breccia zone. Pyrite in small cubes is common in these veins, and in one case beautiful octahedra of sphalerite occur, which are simple model-like twins after (111).

CHEMICAL ANALYSES

Analysis......	I.	*Ia.*	II.	III.	IV.
	Palagonite, Holyoke.	I made anhydrous.	Palagonite, Palagonia.	Palagonite, Seljadalr.	Glass and quartz bearing diabase, Holyoke.
SiO_2	40.35	48.70	41.26	38.96	53.52
Al^2O_3	5.11*	6.17	8.60	11.62	9.70
Fe_2O_3	24.99	30.16	25.32	14.75	8.06
F_2O	3.55	4.28			9.45
MgO	5.48	6.61	4.84	6.29	2.52
CaO	1.32	1.59	5.59	9.13	5.64
Na_2O	.18	0.22	1.06	.68	2.24
Li_2O					
K_2O	1.44	1.76	0.54	0.72	1.50
H_2O—below 100	8.51				1.67
H_2O—above 100	8.51		12.79	17.85	2.16
TiO_2	.20	.24			1.98
ZrO_2					.03
CO_2	None.				1.02
SO_3	"				None.
P_2O_5					.36
S	"				.10
F					
NiO	"				None.
MnO	.22	.27			.26
BaO	None.				None.
SrO	"				None.
	99.86	99.08	100.00	100.00	100.21

* With possible P_2O_5.

Analysis I. Palagonite in gabbroid quartz diabase, New Reservoir, Holyoke Massachusetts. Specific gravity, 1.91. By Mr George Steiger.

Analysis *Ia.* I made anhydrous.

Analysis II. Palagonite. Palagonia, Sicily. S. von Waltershausen, Ueber die Vulcanischen Gesteine. Analysis calculated to 100 after subtracting 10.99 insoluble residue.

Analysis III. Palagonite, Seljadalr, Iceland. By Bunsen. Cited by von Waltershausen, loc. cit. Insoluble residue (4.11) subtracted and the remainder calculated to 100.

Analysis IV. Coarse gabbroid quartz-diabase, containing much palagonite and original quartz and calcite, from an average sample of the very fresh coarse porphyritic rock from the great block that furnished the best palagonite. By George Steiger.

Analysis	V.	VI.	VII.	VIII.
	Normal diabase, mount Holyoke.	Tachylite, Meriden.	Analysis IV minus glass and carbonates.	Holyokeite, mount Tom.
SiO_2	52.68	46.86	60.08	53.83
Al^2O_3	14.14	13.96	11.12	16.36
Fe_2O_3	1.95	5.23	3.76	0.89
F_2O	9.75	4.67	10.47	....
MgO	6.38	7.69	1.84	.13
CaO	9.38	9.42	6.21	9.81
Na_2O	2.56	1.85	2.43	7.89
Li_2O	....	Trace.	......	....
K_2O	.88	2.02	1.60	1.58
H_2O—below 100	Ig. 1.60	1.29	....	.15
H_2O—above 100	....	3.43	....	.36
TiO_2	....	1.13	2.64	.86
ZrO_2	....	....	.04	.02
CO_2	....	2.19	....	7.47
SO_3	....	....	....	....
P_2O_5	....	.15	.48	.11
S	....	....	.13	.17
F	....	Trace.	....	....
NiO	....	Trace.	None.	....
MnO	.44	....	.28	Little lost.
BaO	....	.03	None.	None.
SrO	....	Trace.	None.	None.
CuCu	....	....	....	.14
	99.80	99.92	....	99.77

Analysis V. Compact diabase, mount Holyoke. Mean of two analyses. By G. W. Hawes. American Journal of Science, 3d series, vol. ix, 1875, p. 186.

Analysis VI. Diabase pitchstone from the base of the trap sheet at the "ash bed" at Meriden, caused by the rising of muddy water up into the molten trap from below. By H. N. Stokes. Diabase pitchstone and mud enclosures of the Triassic trap of New England. Bull. Geol. Soc., vol. 8, 1897, p. 77.

Analysis VII. Analysis IV of the glass, quartz, and calcite bearing diabase, with an amount of glass removed equivalent to the amount of water according to analysis I and of calcite and siderite equivalent to the CO_2. The entire freshness of the material and the visible amounts of glass and carbonates justify this.

Analysis VIII. Holyokeite, east foot mount Tom, Hillebrand. Holyokeite, a purely feldspathic diabase from the Trias of Massachusetts. Journal of Geology, vol. x, 1902, p. 508.

Analysis	IX.	X.	XI.	XII.
	Keratophyr, New Haven.	Holyokeite (VIII) minus H_2O and calcite.	Keratophyr (IX) minus H_2O and calcite.	Albite, Danbury, Connecticut.
SiO_2	60.13	65.37	64.77	65.73
Al^2O_3	20.47	19.87	22.05	21.32
Fe_2O_3	1.04		1.12	0.12
F_2O	.72	1.08		
MgO	1.15	.16	.16	
CaO	2.59	.49	.43	1.95
Na_2O	9.60	9.58	10.34	9.66
Li_2O				
K_2O	1.06	1.92	1.72	0.95
H_2O—below 100				0.19
H_2O—above 100				
TiO_2	Trace.	1.04	Trace.	
ZrO_2		.02		
CO_2	3.44			
SO_3	(*)			
P_2O_5		.13		
S		.21		
NiO				
MnO	Trace.	A little lost.	Trace.	
BaO		None.		
SrO		None.		
CuCu		.17		
	99.89			99.92

*Ignition: Includes H_2O.

Analysis IX. Acid dike in the Trias at New Haven. By H. S. Washington. A relatively acid dike in the Connecticut Triassic area. By E. O. Hovey. American Journal of Science, 4th series, vol. iii, 1897, p. 287. The rock is called Keratophyr.

Analysis X. The Holyokeite analysis (VII) with the water and calcite equivalent to the CO_2 subtracted and the remainder calculated to 100 per cent. This is justifiable, since all the amygdules in the rock are of calcite.

Analysis XI. The New Haven dike, analysis IX, recalculated in a way similar to that employed in analysis X. As there was not enough CaO to satisfy the CO_2, it is assumed that about the same proportion of the "ignition" is CO_2 as in the holyokeite analysis, and this is calculated to a mixture of ankerite and calcite, such as is common in the secondary carbonates in the trap. This is justifiable, since the rock analyzed effervesced freely with acid and since iron is "conspicuous by its absence" in the slides examined by Mr Hovey. This procedure perhaps overemphasizes the resemblance between the two analyses, since the New Haven rock is somewhat decomposed and contains some chlorite.

Analysis XII. Albite from Danbury, Connecticut. By F. L. Sperry. American Journal of Science, vol. xxxiv, 1877, p. 392. For comparison with the holyokeite and the keratophyr of Hovey, analyses X and XI.

COMPOSITION OF THE GLASS AND INCLOSING LAVA

The difficult separation of the glass was effected with great skill by Mr George Steiger. He found for the glass the composition given in analysis I, page 112. He remarks that as the mineral was dried at the water bath after making the " Thoulet " separation some of the water coming off below 100 degrees was probably lost before the analysis was started. This would increase a little the close agreement with palagonite, which has a content of water varying from 12.79 to 20.67 per cent. The material dissolved easily and completely in hot HCl, leaving a sandy residue of SiO_2. He found that the glass gave off H_2O at 100 degrees $= 8.57$; at 150 degrees, 2.09; at 200 degrees, 3.12; at 250 degrees, 1.44; at 300 degrees, .71; by blast lamp, $1.15 = 17.02$. I place beside these the analysis of the palagonite of Palagonia (analysis II) and of Seljadalr (analysis III) to show that they are as closely allied chemically as in all their physical characters, and also by way of contrast that of the diabase pitchstone or tachylite from the base of the diabase sheet at Meriden (analysis VI). It is noteworthy that if this latter were made anhydrous it is practically identical with the normal diabase (analysis V). There has been no differentiation. Analysis IV, by Mr Steiger, is made from a large sample of the glass-bearing trap and gives fully the average of the rock. For comparison with this analysis that of Mr G. W. Hawes (analysis V), of the trap of mount Holyoke, from the same sheet, a little farther north, is given. The recalculation of analysis IV, given under VIII, shows that the sample contained an unusual quantity of TiO_2, which explains in part the large amount of FeO. It represents a mixture of holyokeite, normal diabase, and some glass. The H_2O should have been somewhat greater. Attention is directed to analyses X and XI and the explanations given beneath them. The holyokeite is a fresh looking network of albite crystals with many steamholes filled with calcite. As this can not have come from the albite it may have been dissolved calcite as at the reservoir locality. The practical identity of these rocks in fresh condition with albite is remarkable. The identity of the small holyokeite dikes and the lithoidal base surrounding the glass is also made clear by figures 3 and 4 of plate 30.

Thus at many separate localities in the whole extent of the trap sheet this albitic leucocratic differentiate appears, generally in small amount and generally giving indication that water has been the efficient agent in its production. Only in this instance has the other differentiate, the highly basic melanocratic residuum, been preserved, unless some of the fibrous ferruginous material filling or lining cavities which we have called delessite may be this residuum in a devitrified condition.

If we compare the two differentiates with the normal diabase we see that some CaO, MgO, and SiO_2 would be left over if the diabase split into the two extremes, so that it is perhaps not necessary to derive the quartz and oxides from without. It would suffice if water and carbon dioxide were brought in from without. While I have little doubt that in this case the foreign materials were brought in as I have described—that is, as a calcareous mud—since they are found in the immediately adjacent brecciated area, though not in the same slides with the glass, it would perhaps furnish a better general explanation of the presence of these two substances if we accept the remarkable conclusion of Professor Edward Suess * that there is an abundant and frequent present contribution from the deep-seated molten magma of these and other volatile substances. Then we may imagine that, the CO_2 taking part of the Mg and Ca of the magma locally, the immediately surrounding portions of the magma separated into albite and basic glass, rejecting the excess of SiO_2, while an inch away from the glass clots the normal conditions remained unaffected and a normal diabase resulted.

Indeed the enormous quantity of the highly hydrated palagonite present in many places where basic rocks are abundant, together with the great amount of water that is coming up from the interior through open craters, prompts the suggestion that the deep magma may be or may have been much more hydrated than we are accustomed to assume, and that this hydrated magma may have now and again been erupted, and in by far the greater number of cases explosively erupted; hence the general ocurrence of the palagonite as a tuff (see page 121).

In the quantitative classification all the analyses of the Triassic diabase are referred by Professor Iddings to class III, order 5, rang 4: Auvergase, subrang 3: Auvergnose. The diabase pitchstone is placed in the next higher subrang, 2 under Auvergnase, showing the slight chemical difference between it and the normal diabase.† The diabase of Middlefield, Connecticut, is referred by Washington to rang 3: Camptonose, subrang 4: Camptonose ‡ under the same order. The palagonite, assuming it to consolidate into an anhydrous rock, goes under the same class III into order 3: Atlantare and into an unoccupied place, rang 3, subrang 1. The quartz and glass-bearing diabase (analysis IV) goes into class II: Dosalane, order 4: Tonalose, and subrang 3: Hartzase.

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* Ueber heisse Quellen. Verhand. Gesell. Deutsche Naturforscher und Artze," 1892, p. 3.

† Chemical Composition of Igneous Rocks. Professional paper no. 18, U. S. Geol. Survey, 1903, p. 49.

‡ H. S. Washington: Chemical Analyses of Igneous Rocks. Professional paper no. 14, U. S. Geol. Survey, 1903, p. 319. The same analysis is also cited under the next higher subrang as from Meriden, p. 317.

The holyokeite, freed from water and calcite (analysis X), finds place in class I: Persalane, order 5: Canadare, rang 1: Nordmarkose, subrang 4: Dosodic, and a comparison of this with the place of palagonite above gives the extent of the differentiation.* On plate 32 is given the graphic representation of the same differentiation. If the anhydrous part of the palagonite had been calculated to 100 before using, the figure would have been enlarged, so that its base would have had nearly the same length as the silica line in the normal diabase.

THEORETICAL EXPLANATION OF THE FORMATION OF THE HOLYOKEITE AND PALAGONITE AND THEIR INCLUSIONS

THE GENERAL PROCESS

The magma which had dissolved so much quartz and calcite under such temperature and pressure that they could not react on each other soon became unstable. When the point for the beginning of solidification was reached the great feathery pyroxenes in the one variety and the great poikilitic feldspars and skeletonized magnetites in the other were the first to form, shooting out into the very liquid magma, and, floating from place to place in it, were carried sometimes into hotter parts (the very change in the magma made it a better solvent), and then in whole or in part remelted. They thus sometimes inclosed large areas often an inch or more on a side wherein the differentiation and solidification took place in many separate interstitial spaces.

The glass is peculiar in that more than a sixth of its mass is water; more than a fourth iron.

Nearly all the iron and magnesia are concentrated in the glass, while the other differentiate (the holyokeite) is over 92 per cent albite and anorthoclase (see plate 32). We must then assume a sudden differentiation in these interstitial residua. Albite needles bristled out from the cooler borders of these interstitial spaces, crystallization of the albite being perhaps promoted by the feldspar surface already formed as when albite forms on microline, and the quartz albite mixture filled the spaces between the albite needles and thus crowded the water, iron, and magnesia toward the center to form a glass with the minimum of silica.

FORMATION OF THE HOLYOKEITE DIKES

In this way the differentiation into the holyokeite groundmass and the palagonite was effected. Where the development of the great pyroxenes and magnetites had been pushed to an extreme the residual and still liquid magma having about the composition of the holyokeite seems to have been sometimes squeezed out into minute fissures formed by shrinkage or explosions in the newly consolidated schlieren—fissures so small that the large crystals could not enter there. Thus were formed the narrow dikes of almost normal holyokeite, and within them was completed a differentiation into palagonite and holyokeite like that in the coarse diabase ground, and the last of the long albite microlites thrust themselves clear across the palagonite clots from all sides, and in their rapid formation included a core of glass.

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*The keratophyr of Fair Haven freed from H_2O and $CaCO_3$ in the same way finds the same place. Mr Washington calculates the analysis as it stands to the same class and order and to rang 2: Pulaskase and subrang 5: Persodic.

FORMATION OF THE GLASS WITH CALCITE SPHERULITES

In the supersaturated, unstable, and imperfectly blended magma the consolidation was extremely rapid, and antagonistic processes went on almost at the same time and place. The earlier formation of the holyokeite base described above and its growth into the residual glass is only a part of the process. The abstraction of the albite molecule made the glass supersaturated for the Ca and Mg carbonates, while the presence of the mineralizers abnormally prevented it from being supersaturated for iron.

Another form of solidification in this glass (see plate 28, figure 1) then commenced with a minute crystal of calcite, always in the primary form, which sometimes grew in the magma to be 2 to 3 millimeters across, including threads of glass, or a small aggregate of such crystals formed and was surrounded by glass. By the absorption of heat in crystallizing or the abstraction of $CaCO_3$ from the adjacent magma, or both, the crystal becomes the cause of solidification for the latter, and a broad zone of glass uniformly surrounds the calcite.

Again (see plate 28, figure 2), the first grain of calcite causes, as above, the solidification of a thin, spherical layer of glass around itself—just the layer that has been changed and made less fusible by its own crystallization. Outside this layer the magma is in its original condition, and quickly a spherical shell of delicate calcite crystals surrounds the nucleus, and this is in turn the cause of the solidification of a second layer of glass, and this operation is repeated five or six times, forming beautiful spherulites as large as a small shot (3 to 5 millimeters). Sometimes at the end a single crystal grows large and destroys the symmetry. In every case the calcites have sharp angles and lustrous faces, and the delicate feathery groups are so exactly enveloped in the fresh shining glass that even when they are not in spherulites the idea that the calcite has been swept in from some foreign source as solid crystal fragments can not be entertained. Both are ideally fresh and rest in ideally fresh trap, and so a later decomposition can not have furnished the calcite.*

FORMATION OF LITHOPHYSÆ WITH SPHÆROCRYSTALS OF ANKERITE AND QUARTZ

(See plate 28, figures 3, 4, and plate 29.)

In the cases thus far considered there was no excess of water or gas expelled in the formation of the glass, or the pressure prevented its expansion.

In other cases the formation of the glass was accompanied by such expulsion, and the water or gas expanding forms a cavity, after the manner of lithophysæ on a very small scale, in the midst of the glass, and thus probably further increased the amount of the glass by the abstraction of heat. In these highly silicious patches, where silica and calcite have later crystallized out abundantly among the common constituents of the basic rock, conditions may have suddenly supervened (as, for example, a lower temperature) in the liquid magma which would permit the SiO_2 to expel CO_2 from the carbonate. Against the weight of 100 feet of the magma and its viscosity the gas or water vapor expanded to form cavities, sometimes a half inch across, and the walls of these cavities congealed on the instant (from the heat abstracted in the expansion) into filmy spheres of glass like soap bubbles, and these (expanded by the explosion beyond a size they could maintain) shriveled, their plastic walls crumpling into complex wrinkles or buckling into the interior in sharp folds or, where more rigid, cracking and sliding past each other. In other cases the collapse was entire, and the shards of glass are seen by the microscope enveloped in the sphærocrystals of calcite or quartz which follow or scattered abundantly in the surrounding crystalline ground (see the middle of the sphærocrystal in plate 29). When the wall was more plastic it collapsed partly without fracture, and the continued development of the glass on the outside in the midst of the crystallizing magma gave a minute and perfect botryoidal inner surface to the glass cavities.

One can see that these cavities were instantly occupied by solvent fluids—superheated steam, perhaps—because every point of the perfectly fresh fractured or bent glass projecting into the cavity bristles with radiate tufts of calcite or ankerite rhombs, while some of these tufts increase into the large perfect banded and radiate ankerite sphærocrystals which project into the empty cavity. They are partial spheres because they rest on the irregular crumpled film of glass. They seem to derive their banded brown color from the slight oxidation of alternating layers of ankerite, between which are transparent layers of calcite. Treated with HCl under the microscope the lighter concentric layers effervesced abundantly as if calcite. The remaining darker layers effervesced slowly like ankerite. This continued half an hour without complete solution. The slide was then heated and the remnant dissolved rapidly with effervescence. The interior of these cavities is filled by the fine, more or less radiate tufts of water-deposited quartz. More interesting (see plate 28, figures 4 and 5) is the case where the botryoidal cavities, often ½ inch across, are filled with the radiating, deep cobalt blue quartz, whose radiations always start from a point or points on the botryoidal surface and are thus like the chondrites of meteorites. They have grown out as radiate fibrous balls until they have filled the cavities. In cross-section the globular projections of the glass penetrate into the quartz, and when the glass is dissolved the quartz grains present an exact cast of the botryoidal surface or of the spherocrystals of carbonate which have first formed on the walls of the cavity. These fibrous quartz balls have formed during the latter stages of consolidation while the extremely unstable glass and the calcite to which they fit were perfectly fresh. If the quartz had been brought in later by ordinary atmospheric waters, the calcite, ankerite, and glass would sometimes show trace of corrosion. There is still another form of quartz, found in the fresh rock, which is pale blue and fine granular and forms in larger and more abundant grains (see plate 28, figure 5), several quite large ones being often aggregated together. It differs from the other in that it has only a little glass associated with it. It often also fills veins which are of small extent, and in the solid and fresh lava run out to nothing in all directions. Fissures seem to have been formed in the just solidified and still greatly heated rock, and to have been filled by the quartz dissolved in the superheated water in the trap, but at a slightly later stadium than the blue quartz in the glass cavities. This quartz is often granular under the microscope; more often the whole field is made up of the most beautiful sphærocrystals, giving the black cross everywhere. The series is complete, and the succession of minerals is identical, from the glass cavities filled first with ankerite sphærocrystals, followed by radiate quartz, to the great swarms of veins which cement the explosion breccia down the middle of the field, and are composed of bands of ankerite followed centrally by quartz often quite coarsely crystalline or amethystine (see page 97). The extreme purity of the calcite and quartz in the steam holes in the glass is noteworthy.

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* The highly ferruginous glass produced by the refusion of the pyroxene (see page 100) is excluded from this discussion. It is a deep red brown; this is yellow. It solidified in the immediate vicinity of the pyroxene without dissolving any other mineral; this is a residuum of the magma which abnormally held calcite and quartz in solution.

I can conceive how, the small cavities being filled by a fluid (superheated steam?) of different kind from the surrounding magma, the quartz can have been in part carried by osmosis through the film of glass which bordered the cavity and separated the two diverse fluids to form the pure radiate quartz, while the remaining portions of the quartz and calcite were compelled to solidify in the surrounding magma, in which needles, and even large crystals of the normal anhydrous constituents of the diabase, were forming in every direction. In this way all the variants of the quartz-albite ground were produced.

THE PALAGONITE OF SELJADALR

My mind goes back thirty-five years to the old house beside the laboratory of the Hofrath Wöhler, in Göttingen, where that fine scholar, Professor Wolfgang Sartorius von Waltershausen, lectured on mineralogy. I remember the detail with which he discussed the minerals of the Binnenthal and the theory of the feldspars, the series going up to krablite 1 : 3 : 24, and including the amorphous hydrated feldspars of the palagonite group. I little imagined then that a third of a century later I should find palagonite almost in sight of my own college at Amherst and mix it up with sideromelan, but such was to be the case. The memory of those ancient lectures is not so clear as the memory of the genial peculiarities of the good teacher. So when I found a curious glass scattered in small portions in a peculiar facies of the Holyoke trap I turned to Rosenbusch,* who describes and figures the palagonite of Seljadalr as the type of an "Aschentuff," wherein the darker grains with pitchy luster are the original lapilli, which he identifies with the nearly anhydrous sideromelan of von Waltershausen, while the lighter colored intervening bands are the very hydrous products of a secondary chemical decomposition, and form the "dull and earthy" cement of the clastic fragments. It was further stated that while this peculiar tuff was extensively developed in every part of the world the palagonite was found nowhere except in this clastic form. I remembered that von Waltershausen connected the peculiar changes through which he believed the mass to have passed with a submarine deposition, and as the development of the glass in the case I was studying was connected with the unusual introduction of water into the mass I began to search for any description of a similar glass *in situ*, and soon I began to come on discrepancies. As my glass was soft, friable, and easily soluble in weak acid, I had connected it with the palagonites immediately, and as it was jet black and very fresh I had called it sideromelan, supposing it to be anhydrous and like the black parts of the rock from Seljadalr, although the latter was only brownish black. I was thus nonplussed when Mr George Steiger, who had separated the pure material from my Holyoke occurrence with the greatest skill and patience, announced that it contained 17 per cent of water.

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*Gesteinslehre, p. 319; Mic. Phy., ii, 1896, p. 1040.

I then had slices cut from speimens of the "palagonitfels" of Seljadalr (see plate 30, figure 4), which came to the Amherst collection directly from Professor Steenstrup, of Copenhagen, and they seemed to me to be not clastic in any proper sense, but to be portions of a flow somewhat brecciated by steam explosion in place, and an examination of the two good-sized hand specimens confirmed this opinion. Though quite friable they seem wholly homogeneous, and swarms of small pores continue for long distances through the mass and fade away into the compacter portions, while the dark color in the same way fades away into the resin yellow parts. The whole seems to me not a tuff, but a much cracked glass, containing a very few inclusions of a deep red glass and of an indeterminate basalt, and very rarely a minute crystal of augite or plagioclase. The original glass was a fawn color and is still regularly scattered in remnants, often angular in the general mass, but more than half the mass has suffered a slight alteration to a bright yellow glass, sometimes slightly polarizing, and a similar layer is found around all cavities. There is also a thin layer of a brightly polarizing fibrous devitrification substance lining each cavity inside the yellow layer. The peculiar irregular structure of the yellow glass is due to its being made up of collapsed steam holes. Threads of glass, the interior of these variously collapsed and distorted steam holes, the interior of the unaltered steam holes, as well as the small solid spherulites, all show the same brightly polarizing fibrous layer, often several times repeated, and of closely the same thickness. This seems to me to be an original structure in the sense in which the fibrous structure of spherulites is original, and to have been produced by the influence of the H_2O present at the instant of cooling. This water hydrated the glass later for a further distance out from the cavities, changing the original fawn-colored glass to yellow. The repeated expanding and collapsing of the steam has often minutely shattered the glass, producing a micro-brecciated effect, but tracing from one end of the slide to the other the glass is essentially continuous, and I can detect no later microchemical cement, no true fragmental structure, nor any dull pulverulent interstitial matter like what one finds in an ordinary palagonite-bearing tuff, as, for instance, that from the Aschen Kuppel near Giessen, from which I have slides. This shows, even with the naked eye, its tuffaceous character, while the two fine large blocks of the Seljadalr rock seem with a strong lens a cracked but homogeneous resinous glass, which shows over considerable areas a finely porous texture certainly original. A few cavities in the mass are filled with a colorless mineral of very low refraction and cubical cleavage sometimes slightly polarizing, which is doubtless analcite.

The material resembles the Holyoke glass in the appearance of the collapsed steam holes and the fibrous inner devitrification layer, but in its hardness (4.5), color, and greater amount of lime it is more like the basal beds described by me from Greenfield and Meriden, and it seems probable that some part of the palagonite rock, including the specimens I have studied, had the same origin, namely, they were formed as a submarine flow over a bottom made up of volcanic ashes, and the water sometimes explosively penetrating from below the thin crust which had formed beneath the lava and rising up into and blending with the molten mass, caused the sudden formation of glass full of collapsed and distorted steam holes and carried up the foreign fragments of partly decomposed basalt, sideromelan (tachylite), augite, and olivine (and perhaps, also, the shells and infusoria sometimes found in the mass), into the interior, as can be seen distinctly to have happened in the walls of the trap ridges at the localities at Meriden and Greenfield described above. On studying the matter further I came upon the following points confirming this idea:

Bunsen, who first mentioned the locality at Seljadalr, described it as a flow of glass 80 or 100 feet thick, in contradistinction to all the other localities of the palagonite in Iceland, which he calls tuff beds. Von Waltershausen describes it as almost wholly pure palagonite, "with few points of sideromelan," and calls it palagonitfels, though he does not distinctly speak of it as a flow. This is in the same paper in which he describes the sideromelan,* and he describes the latter as black, and with a hardness of 6, and scarcely mentions it at Seljadalr; and as the black parts of the latter rock have a hardness of 4 or 4.5, it is not probable that the dark glass so abundant here (fawn-colored under the microscope) is the same which he analyzed and found anhydrous, nor is it possible that this dark glass is anhydrous. It is dark brown by reflected light and olive green when seen with the lens in the thin-section with transmitted light, and in this it agrees exactly with the "diabase pitchstone" from Meriden which I have described in the paper cited above and which contained 4.72 per cent H_2O. The darker and original portions of the Icelandic glass may be not much more hydrous, while the yellow parts may have become much more hydrous by absorbing the water which frothed it up to produce the many collapsed steam holes.

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* Vulcanischer gesteine in Sicilien und Iceland, pp. 182, 202.

Indeed, the single deep red fragment of glass found in the slide, as mentioned above, is more probably like the original sideromelan. It is plainly foreign and like the tachylite of Säsebühl or Sordavala. Professor von Waltershausen figures and describes the palagonite as a great sheet overlying a soft and fresh tuff,* and finds all the contents of this tuff bed as scattered inclusions in the palagonitfels above. This is exactly as in the Meriden and Greenfield examples, except here, as the flow was over a rusty sand bed, the inclosures have a more foreign and peculiar aspect. Indeed, in an early paper upon the palagonites Professor Rosenbusch admits the possibility that the palagonitfels of Seljadalr may have been a lava flow,† and says that the characteristics of the glass and its alteration can be equally well understood on either supposition.

This palagonite has been the subject of most peculiar theories which one may recall briefly. Bunsen thought it due to the smelting of the normal basalt with 13 parts of CaO or K_2O, and imitated it by this process. Von Waltershausen developed an elaborate theory of its formation from a submarine tuff bed, where largely by the action of the sea water the adhydrous glass sideromelan was changed into a hydrated porodine cement which united the whole in a solid mass. This cement formed a series of hydrated feldspars. Professor Rosenbusch gave the correct explanation of the origin and alternation of the palagonite and its agglomeration in tuff beds, but seems to have chosen as a type of his "Aschentuff" one of the few true and rare flows of the material.

Résumé

We may distinguish the following steps in the consolidation of the palagonite:

1. At the beginning of the process a minute globule of superheated H_2O caused the formation around itself of a radiate-fibrous spherulite, brightly polarizing with black cross and positive sign, which may be also concentric structured by slight oscillations in its rapid growth. ‡

2. The same H_2O may be able to expand, and then the radiate-fibrous layer is produced by the same cause around the inside of the cavity. The cavities may be spherical or drawn out by flow. The solid spherulites may be deformed or mutually impress each other or several be included in the continued growth, showing that they were formed in the still plastic magma.

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* Loc cit., pp. 481, 483.

† Neues Jahr. f. Min., 1872, p. 165.

‡ It is necessary to free glass from gas bubbles to prevent devitrification.

3. The cavities may be isolated or so abundant as to froth considerable areas into a porous mass.

4. The expansion of the gas may be explosive and the collapse immediate, and the microscopic crystalline pellicle may be brittle, and its parts crack and slip on each other (plate 29, figures 1 and 2), or plastic and wrinkled into the shrunken cavity like a wet cloth (plate 28, figure 2), still very clearly showing its identity and differentness from the inclosing glass by the fibrous and brightly polarizing character.

5. The H_2O is then slowly absorbed into the glass, and so far as it goes the pale brown glass is changed into a bright yellow slightly polarizing glass.

6. This change, extending outward from several adjacent centers, leaves angular, often concave-sided remnants of the brown glass which exactly simulate lapilli. It is also possible that the repeated small explosions might occur when part of the glass had already solidified and it be shattered and the fragments moved and enveloped in the still liquid glass.

7. The H_2O has expanded in a swarm of pores, which are elongated by flow and then lined by a perfectly even layer of the fibrous crystalline material. This crystallization is thus plainly subsequent to the appearance of the H_2O as a liquid and can not be called on to explain the isolation of the H_2O by the formation of an anhydrous silicate in the hydrated glass after the manner of explanation of the lithophysæ proposed by Professor Iddings. Indeed, when I examined the lithophysæ in the Yellowstone their size and abundance seemed to me to demand some more abundant source than the glass itself for a part at least of the H_2O. Here I should derive at least the larger part of the H_2O from the sea bottom and think of it as introduced with the foreign tuff fragments found in the mass either simply by a picking up of the wet material as the lava flowed over it or by more local and explosive penetration of the thin solid bottom layer which would naturally form and generally protect the liquid mass from the wet bottom.

Discussion by Alfred R. Lane

When Professor Emerson was kind enough to show to the Society at Washington his specimens of "plumose diabase," with the large arborescent growths of augite, I was very much interested and examined them rather particularly, the more so because in one point they led my mind to an inference different from that which Professor Emerson reached. He thought that the coarse outgrowths of augite showed extra rapid crystalline growth, produced by extra rapid cooling of the diabase by the inclosure. To me they seemed probably the result of extra slow growth, in accordance with the usual rule, "the slower the cooling the coarser the grain." As I conceive it, when inclosures were thus surrounded they cooled the surrounding lava sooner, not down to solidification, but down to the point where augite could begin to form, and the surrounding lava remained in the range of temperature of augite formation longer, only passing below when the rest of the flow thereabout cooled below the temperature of augite formation and finished solidification.

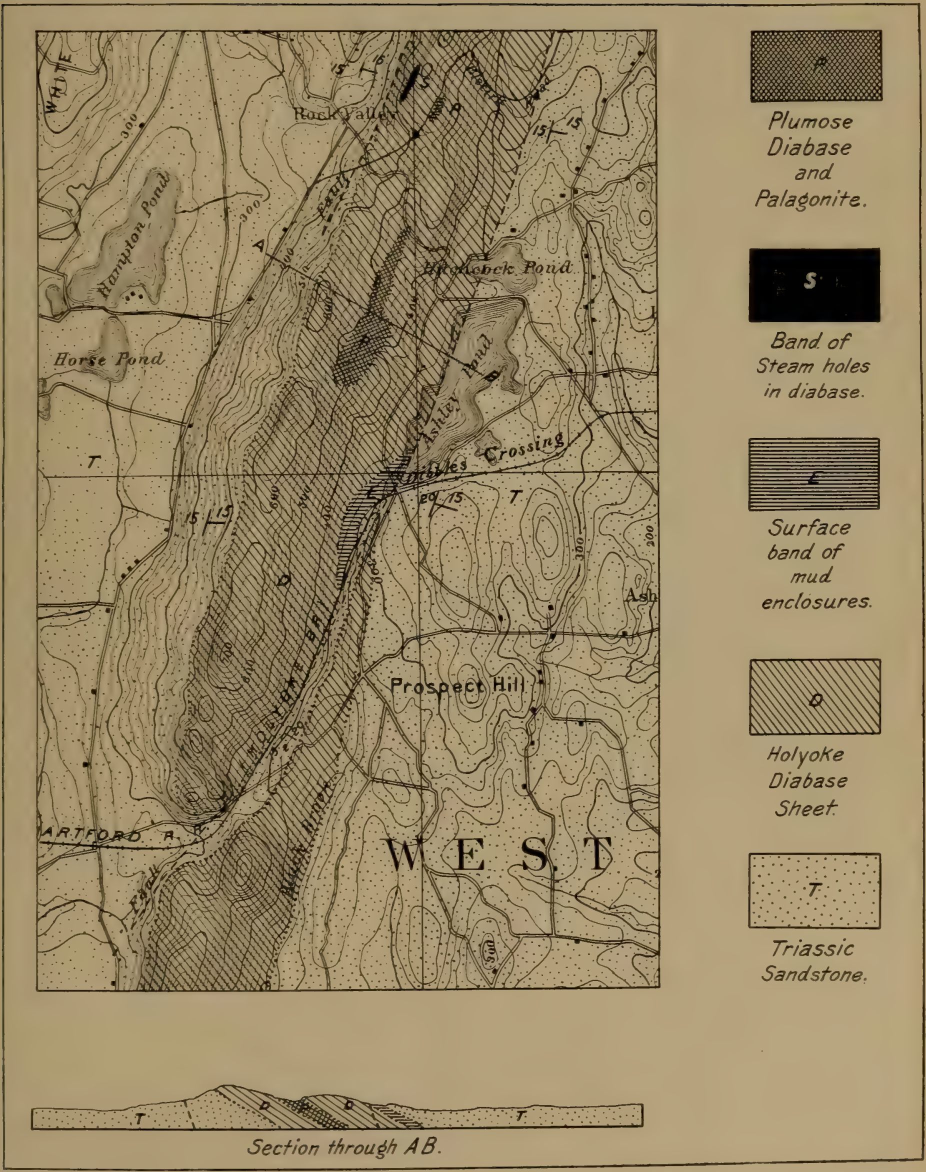
I do not mean to say, however, that chemical relations and the introduction of augite molecules may not also have been an important factor.

There are a number of other cases of similar phenomena that I have seen and would explain in a similar way—"plumose" growths of augite along the contacts of gabbros and associated red rocks, and on the north side of Nahant and elsewhere contact lines between successive gushes or jets of igneous rock.

Mr Lane has been so kind as to send me a copy of the above remarks, which were called out by my explanation of the long-bladed pyroxene as a case of rapid crystallization caused by the cooling effect of the intruded mud.

This was in a brief preliminary description of the occurrence, of which I have preserved no record, and I can not now remember how far I tried to enumerate all the factors concerned in the explanation of the peculiar long-bladed type. I certainly gave more weight to the cooling effect than I should now do, since the thin schlieren containing the long crystals have traveled so far from the central mud breccia and contain therefrom so little material in solution (H_2O, $CoCo_3$, SiO_2) that the temperature differences seem to me to have been equalized long before they reached their present relation and approached crystallization.

None of these peculiar effects occur in the immediate vicinity of the mud. There is here a somewhat coarser grain, for which I welcome the ingenious suggestion given in the last sentences of the above remarks; but for the narrow schlieren carried out from this central area, where the pyroxenes are a hundred times as long as in the adjacent trap, the principal cause for the difference in size seems to have been the chemical differences in the two magmas. The extensive development of skeleton crystals and micropegmatitic structures and the simultaneous crystallization of quartz and calcite, all in the midst of glass clots, speak for rapid crystallization.


WHITE
Rock Valley
Hampton Pond
Horse Pond
Ashley Pond
Crossing
Prospect Hill
Ash
HARTFORD R.R.
WEST
A
B
T
P
D
E
S
15
20
300
400
500
600
200
P
Plumose Diabase and Palagonite.
S
Band of Steam holes in diabase.
E
Surface band of mud enclosures.
D
Holyoke Diabase Sheet.
T
Triassic Sandstone.
Section through AB.

MAP OF TRAP SHEET ACROSS HOLYOKE AND SECTION

Scale: 1 mile to the inch

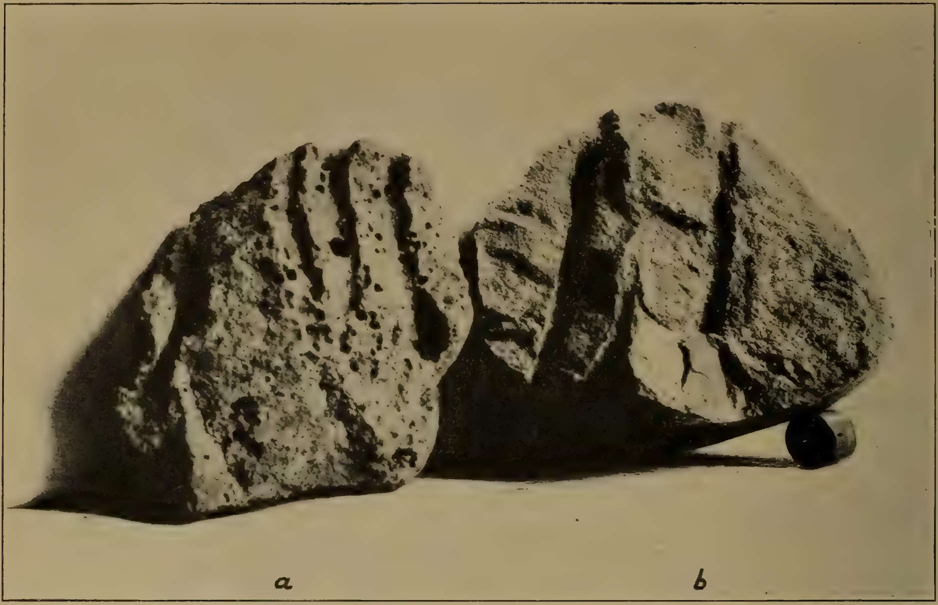


FIGURE 1.—TUBULAR CAVITIES (× ½)

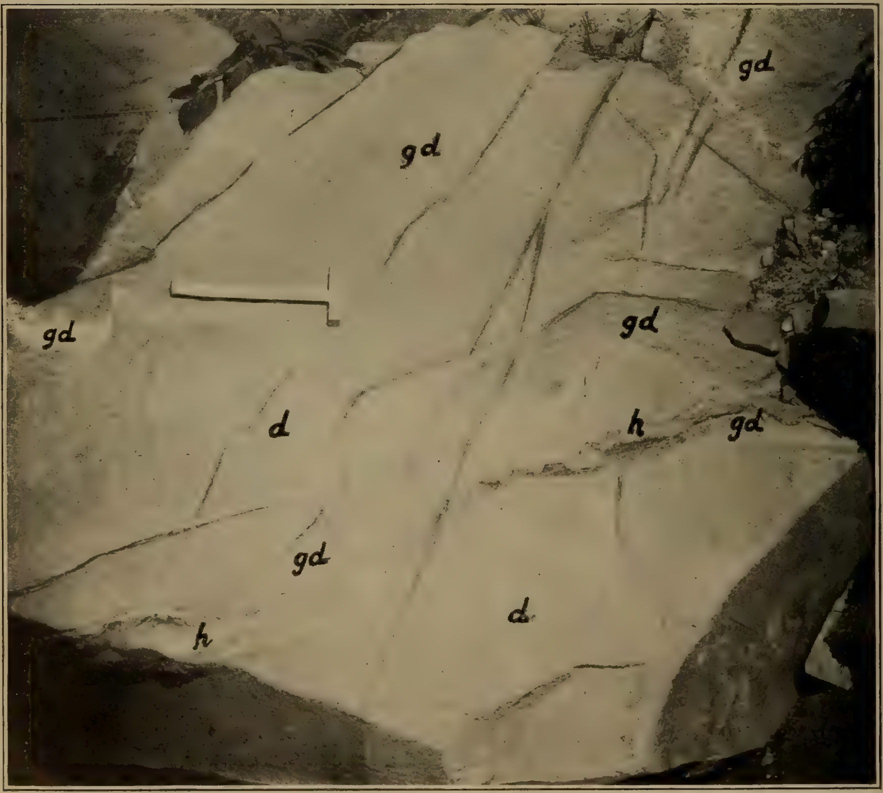

gd
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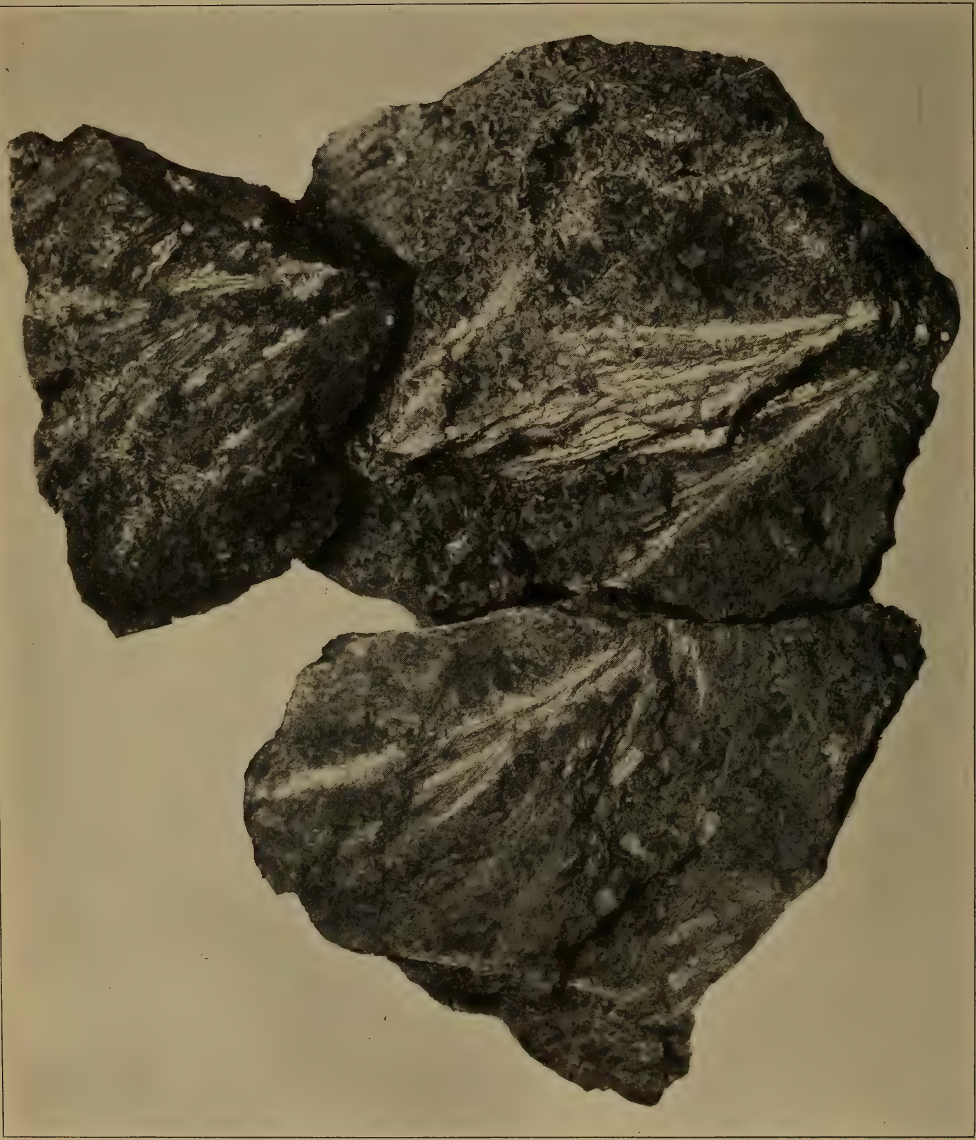
FIGURE 2.—BLOCK OF FRESHLY BLASTED TRAP

TUBULAR CAVITIES AND GROUP OF DIKES



LONG PLUMOSE DIABASE ($\times \frac{5}{6}$)

The drifting of the long crystals into an adjacent portion of the magma, where they were remelted, would harmonize with Mr Lane's suggestion of a slower crystallization in the schlieren, as would, perhaps, also the general development of an incipient differentiation.

Explanation of Plates

Plate 24.—*Map of Trap Sheet across Holyoke and Section*

Showing Holyoke diabase, plumose diabase, palagonite, and surface layer of mud inclosures. The section is along the line *AB* (see page 95). Scale 1 mile to the inch.

Plate 25.—*Tubular Cavities and Block of Trap*

Figure 1.—Tubular cavities (× $\frac{1}{2}$).

a. Tubular cavities formed in the superficial portion of the trap sheet by the escape of steam. *b.* The same found inverted at the base of the sheet. They illustrate the underrolling of the surface layer of the advancing sheet (see page 94).

Figure 2.—Block of freshly blasted trap.

This photograph of a block of freshly blasted trap (*d*) from the central brecciated band shows above the hammer the coarse gabbroid diabase (*gd*) and schlieren of the same. The one under the hammer faulted. Below is a branching dike of the coarse gabbroid diabase, having a thin central dike of holyokeite (*h*), which is also faulted. Below the hammer the holyokeite is broader and light colored. It is just above the *h*. At the right it is a wavy white narrow band along the upper border of the lower branch of the coarse dike (see page 107).

Plate 26.—*Long Plumose Diabase* (× $\frac{5}{8}$)

The pyroxene crystals have shot out into flat blades, which branch with small angle and are grouped in tufts all bent in a common direction by the motion of the lava, as grass leaves bend in the wind. The central band bends forward and so does not show its curvature (see page 99).

Plate 27.—*Pyroxene, Magnetite, and Plagioclase*

Figure 1.—Flat-bladed pyroxene (natural size).

This pyroxene is from the central portion of plate 26, showing the central twinning suture, and the transverse basal parting (see page 99).

FIGURE 2.—Partially remelted pyroxene crystal (× 40).

The right central part is the pyroxene remnant (*h*) with the prismatic cleavage horizontal. In the transition band the basal parting is developed (vertical in the figure) and continues both in the broad, dark-shaded band (*g*), which is non-polarizing glass, and in the broad, lighter shaded bands on each side, which are devitrified glass (*dg*), and which ends outwardly in a fringe of glass threads full of magnetite grains—the original resorption rim (*rr*) around the outside of the crystal. Outside this is the quartz ground full of feldspar microlites. Then comes a broad band of calcite grains (*c*), containing glass clots (*g*), which is intercrystallized with the normal pyroxene-plagioclase ground (see page 100).

FIGURE 3.—Skeletonized magnetite and poikilitic plagioclase.

If a diameter be drawn from the lower right to upper left the left half of the figure is a single plagioclase crystal, coarse poikilitic with augite on the upper and fine poikilitic on the lower half. The large black spots are clear yellow glass. The lines of magnetite run across the slide like the strings of a harp. They seem to blend in broad black patches, because they inclose portions of the same yellow glass, which photographs black (see page 102).

PLATE 28.—*Glass Spherulites*

The first four drawings on this plate are of single particles of glass, which were surrounded by the bluish aphanitic holyokeite ground and inclosed in the coarse glass-bearing diabase.

FIGURE 1.—Transparent calcite (× 6).

The crystal is a rhombohedron of colorless transparent calcite, with lustrous faces, inclosed in jet black palagonite, which has penetrated the crystal along the twinning plane $-\frac{1}{2}$ R and also irregularly. The finer lines are cleavage (see page 118).

FIGURE 2.—Calcite spherulite (× 15).

A central grain of calcite, not seen in the drawing, is surrounded by a sphere of glass, which forms a nucleus around which a layer of calcite rhombs crystallize, followed by a second layer of glass, and so on. The outer layer of calcite is made of large and perfect crystals, always the primary rhombohedron (see page 118).

FIGURE 3.—Calcite spherulite (× 4).

The spherulite is broken across so as to show the drusy surface of a calcite sphærocrystal and the blue radiate quartz. The black glass shows a botryoidal interior from collapse (see pages 102, 119).

FIGURE 4.—Collapsed glass cavity (× 2).

Showing on the black glass wall distinct crystals of calcite and sphærocrystals of calcite-ankerite and deep blue quartz radiate from the edges (see page 119).

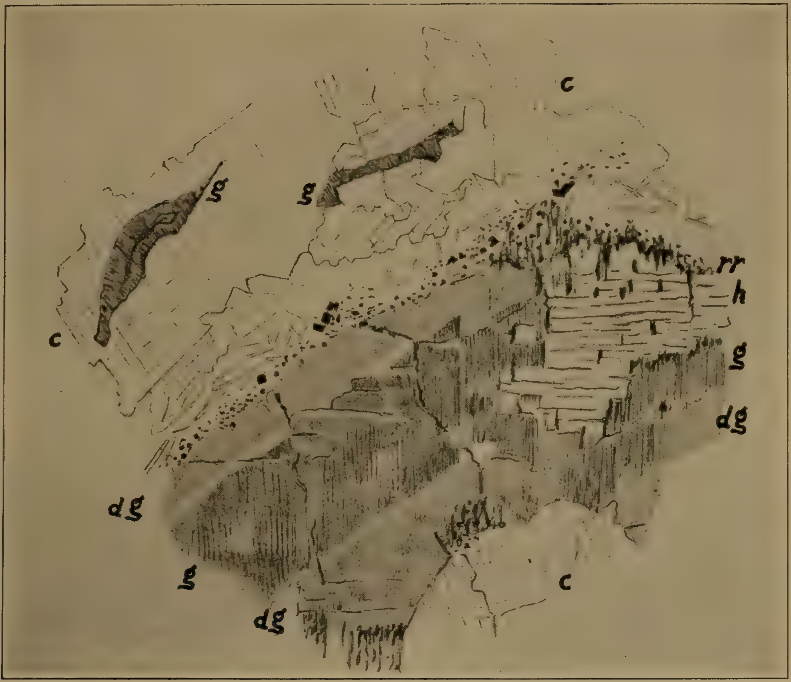


Figure 2.—Partially remelted Pyroxene Crystal (× 40)

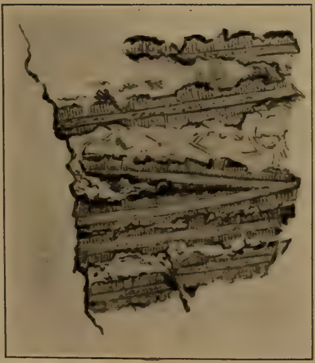


Figure 1.—Flat-bladed Pyroxene

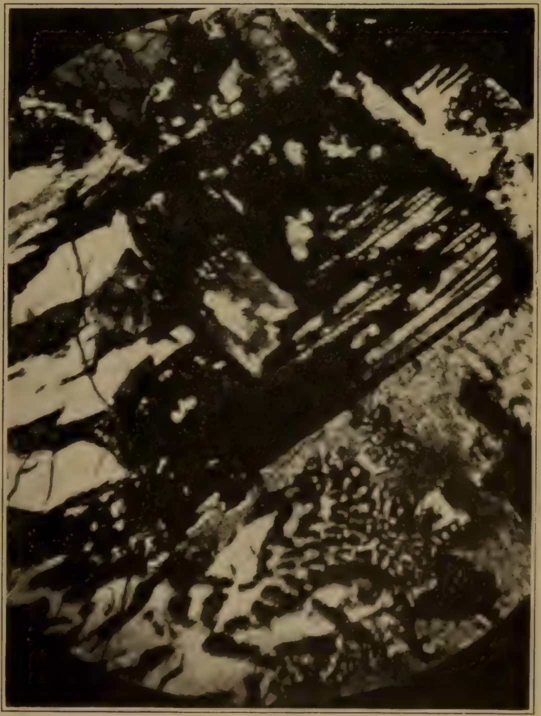


Figure 3.—Skeletonized Magnetite and poikilitic Plagioclase

PYROXENE, MAGNETITE, AND PLAGIOCLASE

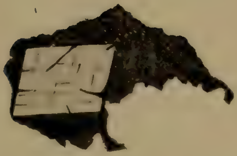


FIGURE 1.—TRANSPARENT CALCITE (× 6)

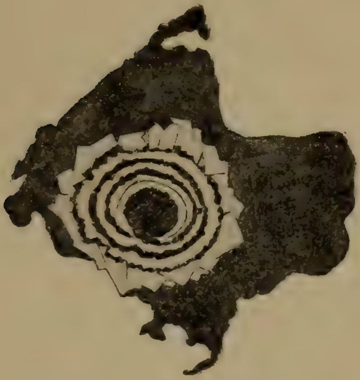


FIGURE 2.—CALCITE SPHERULITE (× 15)

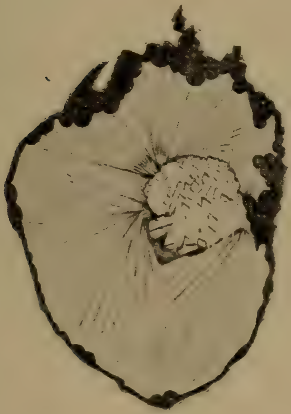


FIGURE 3.—CALCITE SPHERULITE (× 4)

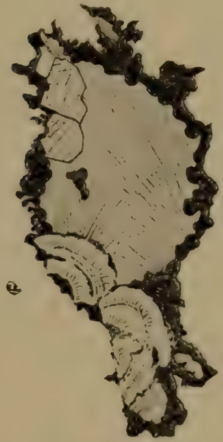


FIGURE 4.—COLLAPSED GLASS CAVITY (× 2)

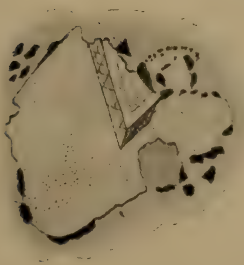


FIGURE 5.—CAVITY IN COARSE PORPHYRITIC DIABASE (× 4)

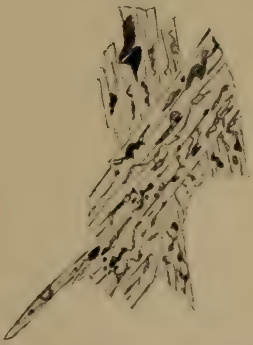


FIGURE 6.—ARROWHEAD TWIN OF LABRADORITE

SPHERULITES IN GLASS

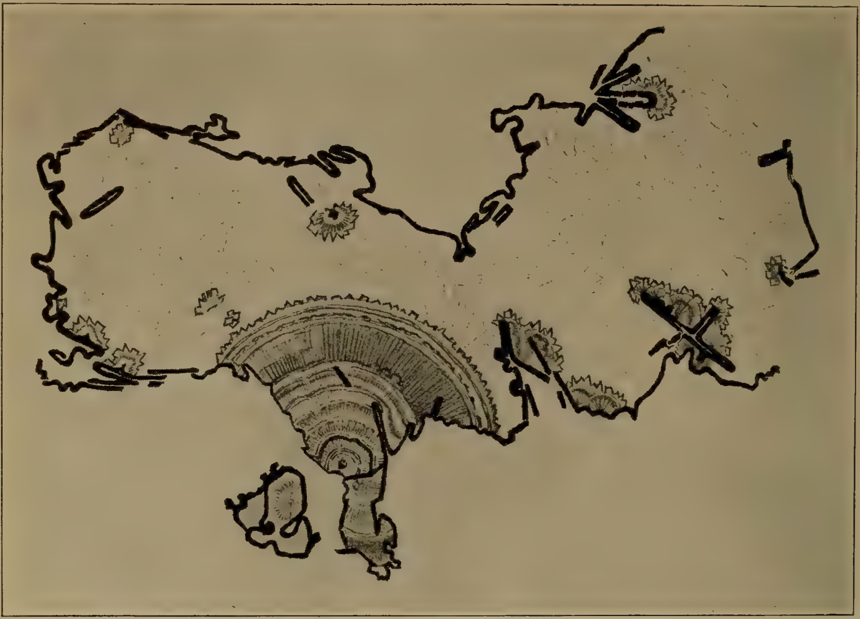


FIGURE 1.—PARTLY COLLAPSED GLASS-LINED CAVITY (× 20)

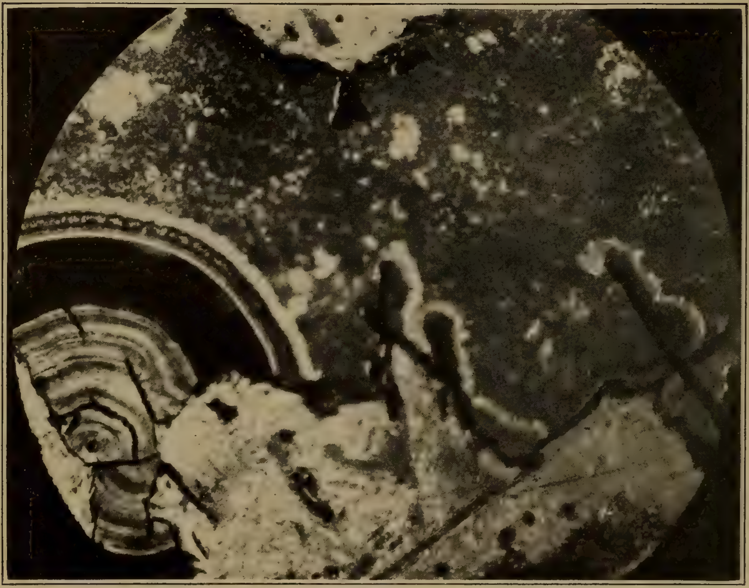


FIGURE 2.—CENTRAL PORTION OF FIGURE 1 (× 32)

GLASS-LINED CAVITY

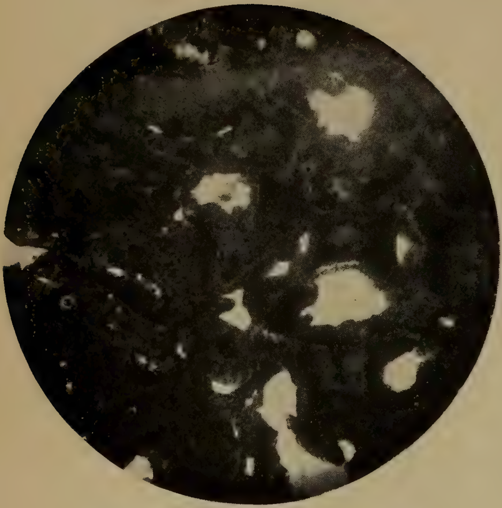


FIGURE 1.—SELJADALR PALAGONITE (× 20)

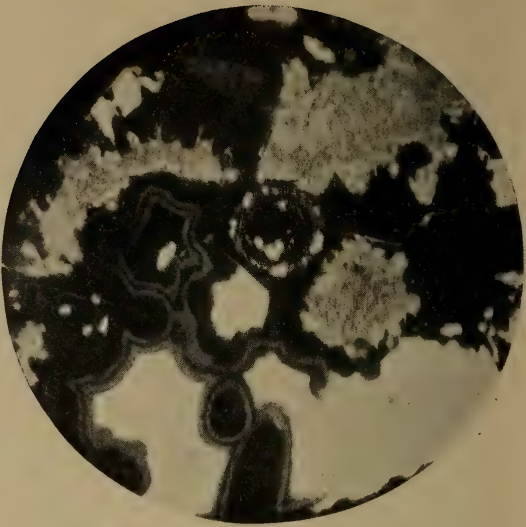


FIGURE 2.—BOTRYOIDAL DENTRIFIED GLASS MASS (× 32)

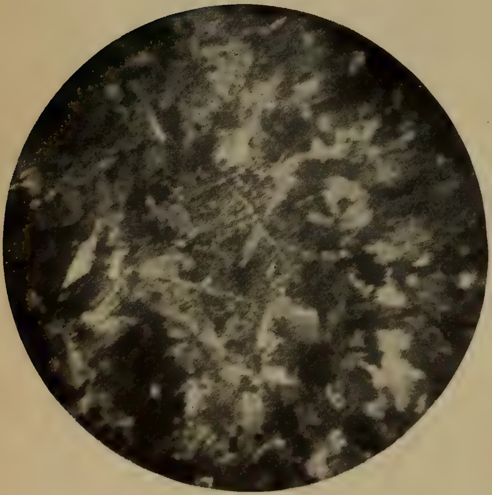


FIGURE 3.—HOLYOKEITE GROUND OF THE COARSE PORPHYRITIC DIABASE (× 32, polarized light)

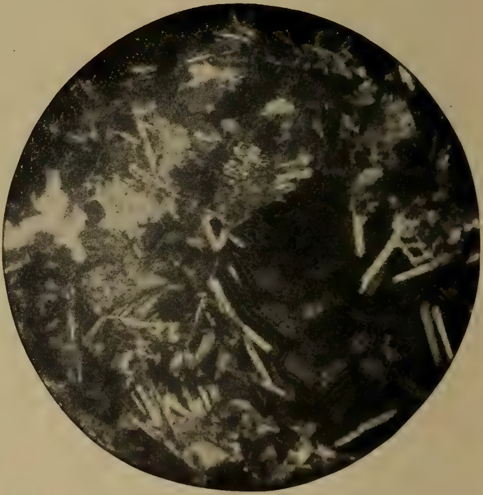


FIGURE 4.—MATERIAL FROM A HOLYOKEITE DIKE (× 32, polarized light)

PALAGONITE, DEVITRIFIED GLASS, AND HOLYOKEITE MATERIAL

FIGURE 5.—Cavity in coarse porphyritic diabase (× 4).

A large striated magnetite and a calcite project into the cavity, which is partly bordered by black glass. The cavity itself is filled by pale blue fine granular quartz (see page 102).

FIGURE 6.—An arrowheaded twin of labradorite, full of grains of pyroxene and glass (see page 102).

PLATE 29.—*Glass-lined Cavity*

FIGURE 1.—Partly collapsed, glass-lined cavity (× 20).

The cavity is in a coarse porphyritic glass-bearing diabase. It contains tufts and a sphærocrystal of calcite and ankerite and is filled with fine granular quartz. The black border is a yellow-brown non-polarizing glass greatly wrinkled and broken by collapse, so that isolated fragments are found in the quartz, the sphærocrystal, and the surrounding rock. It is missing in part only because the whole cavity is not preserved in the slide. Delicate tufts of brown ankerite crystals have formed on many projecting points, and one has developed into a beautiful sphærocrystal having alternate layers of white calcite. The center is filled with limpid quartz, which polarizes in a multitude of black crosses and so reveals a minutely radiate texture. A part torn from the main bubble appears isolated below.

FIGURE 2.—Central portion of figure 1 (× 32).

The ground below is the fine grained quartz-albite halo of holyokeite surrounding the glass (see page 119).

PLATE 30.—*Palagonite, devitrified Glass, and Holyokeite Material*

FIGURE 1.—Seljadalr palagonite (× 20).

The colorless spaces filled by secondary analcite are variously collapsed steam holes, into one of which a bent thread of glass projects. They are bordered by yellow fibrous devitrified glass, and many similar bands appear in the fawn-colored glass, derived from wholly collapsed or shattered bubbles (see page 121).

FIGURE 2.—Botryoidal devitrified glass mass (× 32).

This mass is from the coarse diabase with resorbed pyroxenes. The upper third of the figure and the gray spot to the right of the center is the fine grained quartz albite holyokeite. The three large white spots are the finely radiate quartz-filling of the irregular cavity formed by the partial collapse of the steam hole. A few calcite grains mark the boundary of a perfect spherulite near the center. The outer boundary of this has suffered a slight fibrous devitrification. The center and the surrounding clear yellow glass is mostly non-polarizing except when it grades into an agate-like banded part which polarizes softly (not shown in slide). Where it borders on the cavity there is a double band of lighter color and even thickness, fibrous, brightly polarizing, and showing everywhere the black cross in perfection (see page 105).

Figure 3.—Holyokeite ground of the coarse porphyritic diabase (× 32, polarized light).

Showing its peculiar radiate hyalopilitic texture. The larger needles contain a dark central thread of glass (see page 106).

Figure 4.—Material from a holyokeite dike (× 32, polarized light).

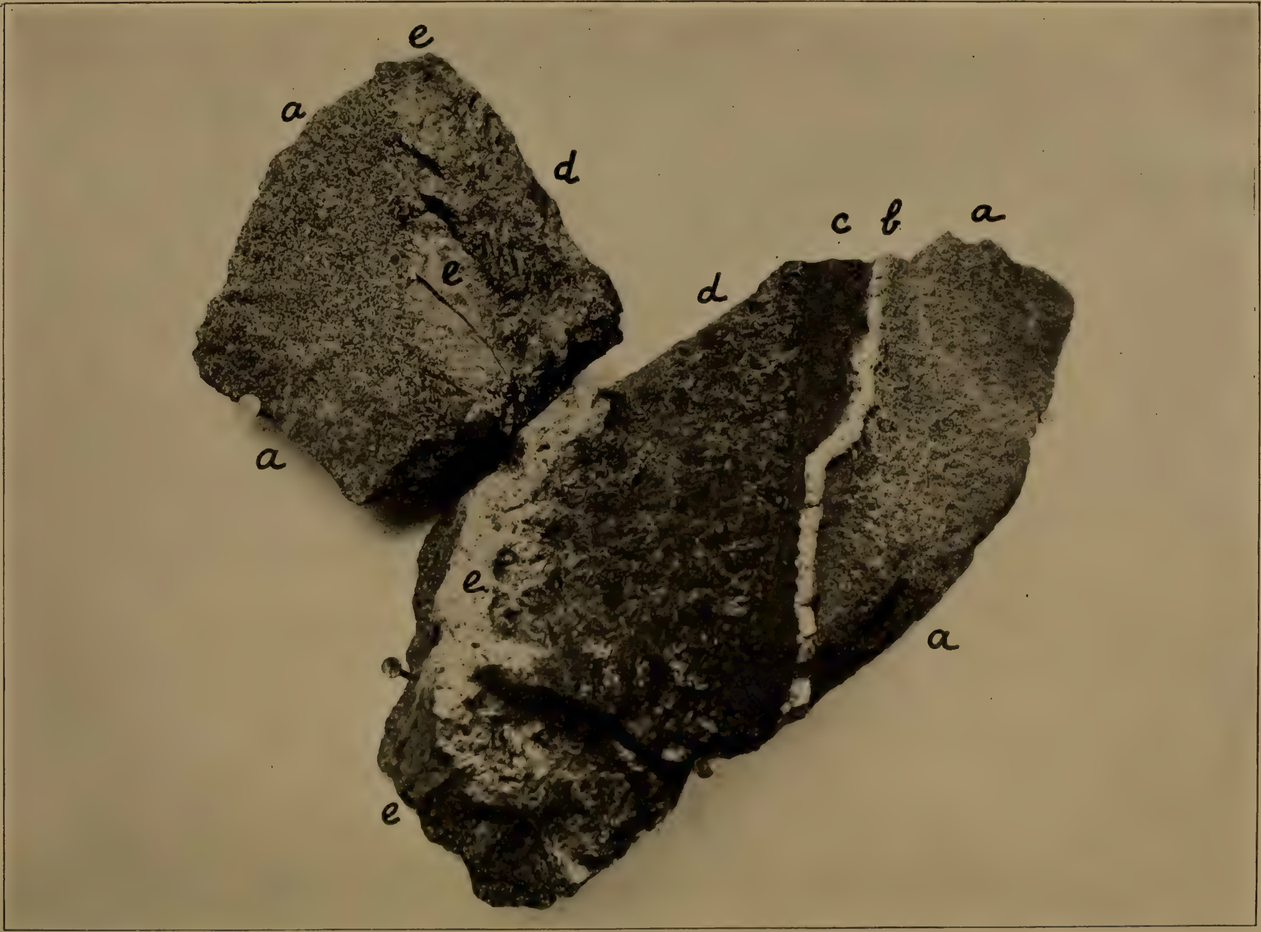
Showing the same fine hyalopilitic texture as in figure 3. Many albite needles penetrate the large glass portion on the right and show a central thread of glass (see page 106).

Plate 31.—*Material from a Composite Dike* (× ½)

This material consists of basic diabase aphanite (*c*), plumose diabase (*d*), holyokeite (*e*), and quartz (*b*) in normal diabase (*a*) (see page 108).

Plate 32.—*Graphic Representations of the Constituents of the normal Holyoke Diabase and the extreme differentiation Products; the Palagonite and Holyokeite*

The method employed is that of Brögger as modified by Hobbs (see page 117).


e
a
d
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c
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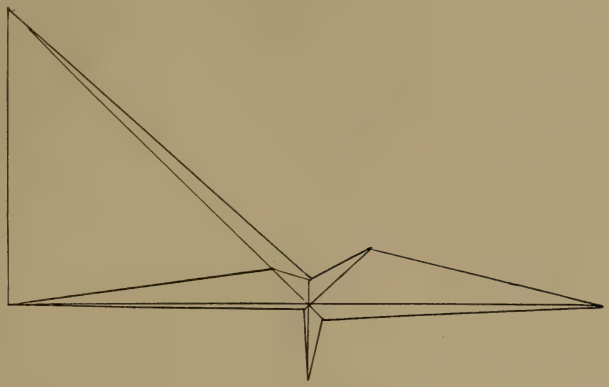
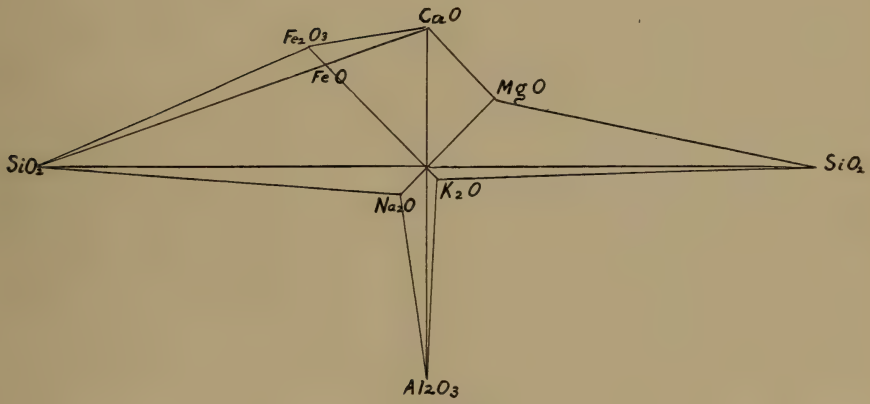
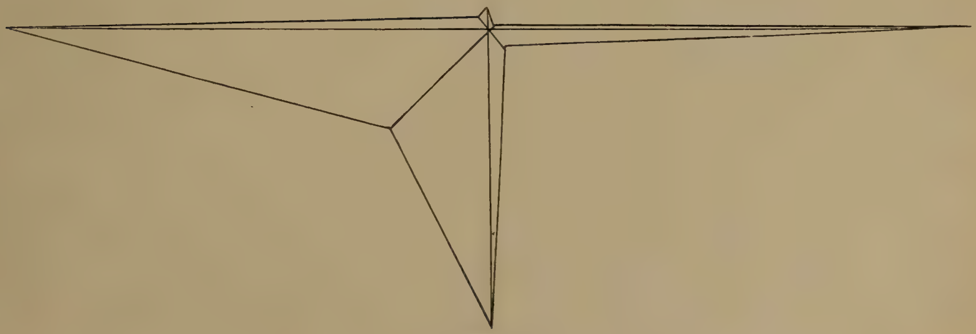
MATERIAL FROM A COMPOSITE DIKE



PALAGONITE

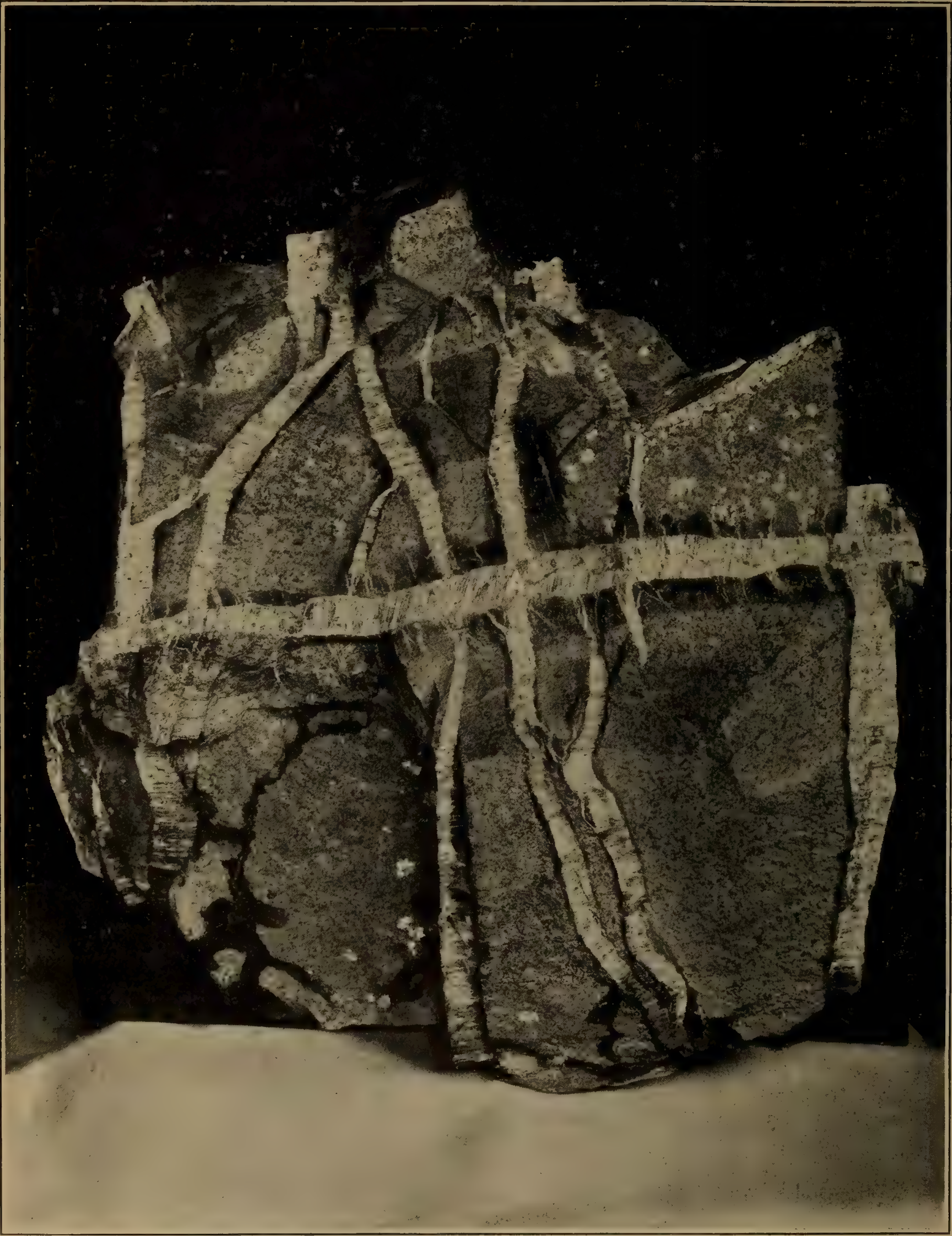

CaO
Fe₂O₃
FeO
MgO
SiO₂
SiO₂
K₂O
Na₂O
Al₂O₃

NORMAL DIABASE



HOLYOKEITE

GRAPHIC REPRESENTATIONS OF THE CONSTITUENTS OF THE NORMAL HOLYOKE DIABASE AND THE EXTREME DIFFERENTIATION PRODUCTS; THE PALAGONITE AND HOLYOKEITE



BLOCK OF MASSIVE SERPENTINE

This block is 30 x 30 x 27 inches and is traversed by veins of asbestos

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 16, PP. 131-136, PLS. 33-34 MARCH 10, 1905

ON THE ORIGIN OF VEINS IN ASBESTIFORM SERPENTINE

BY GEORGE P. MERRILL

(Read before the Society December 30, 1904)

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INTRODUCTION

As a result of a recent trip to Thetford mines, in Canada, the writer was able to secure for the National Museum, and through the courtesy of Mr B. J. Bennett, manager of the King Brothers mines, an unusually fine block of serpentine, with veins of the fibrous form, chrysotile (the so-called asbestos), which seems worthy of a special description, even though little, if anything, new is deduced relative to the origin of the material.

DESCRIPTION OF THE SPECIMEN

The block, as now on exhibition in the Museum (plate 33), is some 30 by 30 by 27 inches (76.2 by 76.2 by 68.6 centimeters) in dimensions. As seen in the plate, it is traversed from left to right by one large vein of the asbestos (chrysotile), with others not quite so wide, in an approximately vertical direction.

Confining our attention first to the horizontal vein (some 40 millimeters in maximum width), it will be noted that the fibers are not in all cases continuous from wall to wall, but that they are intercepted about midway by a narrow band of massive material, which shows only as a dark wavy line in the illustration. This is a very common occurrence.

Though the vein is separated sharply from the massive material, there are numerous short, narrow veinlets, some almost microscopic, extending into it from either side, above and below. These are not over 20 to 40 millimeters in length and 1 to 5 millimeters in width. Referring to the approximately vertical veins (some 30 millimeters in maximum diameter), it is to be noted that they are often branched, and that, further, the branches are sometimes smallest at their point of attachment. At first glance, these vertical veins appear to be cutting across the horizontal. In reality such is not the case; with possibly one exception each and all fray out—that is, split up abruptly into a number of small veinlets, which terminate before reaching the larger. This feature is not readily apparent in the plate, owing to the half-tone process used in reproduction, but is easily seen in the photograph, and better yet in the specimen. In a single instance (see *A* in plate 33) the appearance is as if the vertical vein had at one time been continuous above and below the horizontal, but had been pinched out by some subsequent movement of the mass. Although not well shown in this particular specimen, these veins, as is well known, are never continuous for any great distance, but pinch out to mere knife-like edges at the ends, or are variously forked and frayed, as indicated in the drawings in figures 1 and 2. A common and abrupt change in the form of the veins is shown in figure 1, representing a block of serpentine some 8 by 10 by 3 centimeters in thickness, and showing the same series of veins as they appear on opposite sides of the block.

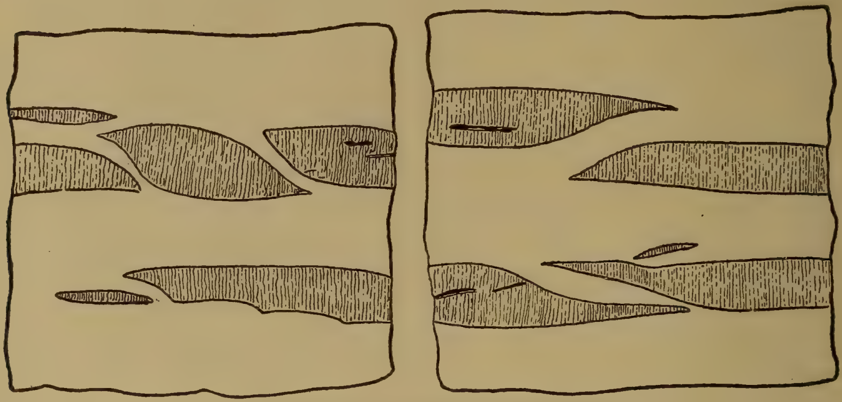

FIGURE 1.—*Veins on opposite Sides of Serpentine Block.*

Shading represents veins, white portion serpentine.

In all cases the vein material separates readily from the massive, indicating that the fibrous portions originated through crystallization in an open fissure, though it does not necessarily follow that the fissure was open to its present width when the filling process began.

Referring to the fibers themselves, it may be stated that they are soft, tough, and pliable, with a silk-like sheen or luster. In cross-section they are flattened or cylindrical, in this respect in strong contrast with the fibers of the true asbestos (a variety of amphibole), which are polygonal. In diameter they vary down to .002 of a millimeter, and even less.

ORIGIN OF THE VEIN CAVITIES

The origin of these veins and the fibrous structure of the filling material are involved in some obscurity. The fact that the same mineral occurs in both massive and fibrous forms, so closely and intimately associated, is certainly striking. That the vein material is of a later origin than the massive rock is self-evident, but why the later formed material should be always fibrous and of a distinct crystalline structure, while the older is massive and nearly or quite amorphous, it is difficult to say, and existing literature is discreetly silent on the subject. The massive serpentine rock is itself described as an altered diorite or doleritic rock, rich in olivine.* The time that the present writer was on the ground did not permit a thorough investigation on this point, but blocks were noticed which, though highly altered, showed beneath the microscope structures more nearly that of massive enstatite rocks or pyroxenites. There is, however, apparently no doubt that they are altered highly magnesian igneous rock. Now, the process of hydration (serpentinization) in rock of this class must, provided there is no loss of material by

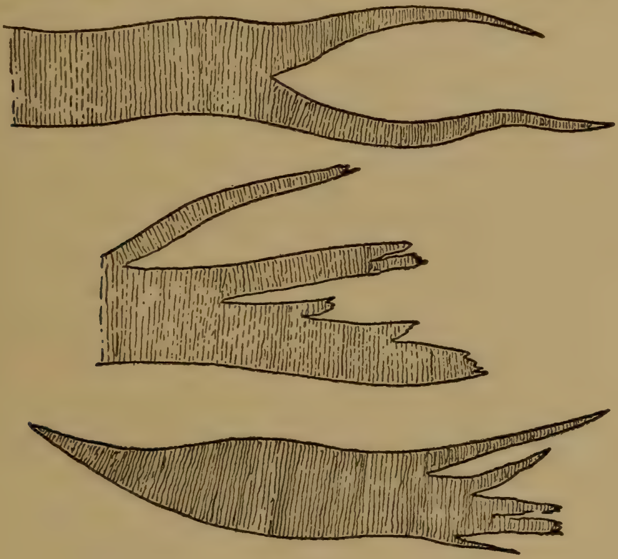

FIGURE 2.—*Asbestiform Veins in massive Serpentine.*

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*Asbestos and asbestic, by R. H. Jones, 1897, p. 108; also R. W. Ellis, Trans. Am. Inst. Min. Engs., vol. xviii, 1889, p. 322.

solution, result in expansion. T. S. Hunt showed * that the passage of olivine into serpentine under such conditions would result in an increase in bulk amounting to 33 per cent.† That some material is almost invariably lost we have abundant proof. Nevertheless, expansion at some stage in the serpentinizing process usually results, and it is to the incidental readjustment of the rock mass that is commonly attributed the characteristic jointed condition and the slickensided surfaces.‡ These joint faces are often coated with platy and fibrous material, and bear out the author's opinion, expressed elsewhere,§ to the effect that ordinary asbestiform structure among amphibolic and pyroxenic minerals is due to shearing stresses, the elongation taking place along the line of least resistance and being in some cases but an exaggeration of the normal cleavage property. Such structures are, however, quite different and independent of the veins we are now discussing. For the production of these last quite different causes need be evoked.

Fritz Cirkel, in a paper on the occurrence and mining of asbestos in Canada,‖ mentions the two prevailing theories. The one, that the fissures were formed in the serpentine magma as a result of cooling and contraction and subsequently slowly filled through a process of lateral secretion, and the other, seemingly ignoring the fissures, deriving the asbestos from the alteration of olivine and serpentine at high temperatures. No preference is indicated for either theory, nor does he express independent views of his own.

In the course of a discussion with Professors T. N. Dale and J. F. Kemp the suggestion was advanced by the one that the fissures might be the result of tension or a stretching movement, and the other that they are due either to dynamic causes or produced by a shrinkage due to a loss in silica in the process of alteration (serpentinization). If due to tension, it would seem to the writer that they should conform to one or more definite and determinable directions. Such, however, is apparently not the case, the veins being, as a rule, even more irregular in their direction and distribution than shown in our plates and figures, and the opinion held by the present writer is more in harmony with the hypothesis of shrinkage.¶

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* Mineral Physiology and Physiography, p. 506.

† According to Professor Sollas but 30 per cent. See Geol. Mag., vol. ii, 1895, p. 259.

‡ See "On the serpentines of Montville, New Jersey." Proc. U. S. Nat. Mus., vol. xi, 1888, p. 105.

§ The Non-Metallic Minerals, p. 183.

‖ Zeit. für praktische Geologie, vol. ii, 1903, p. 123.

¶ The possibility of the vein cavities being produced by a torsional stress could be definitely decided could it be shown that the veins were themselves of more recent origin than the joints, since, under these conditions, any probable stress would find relief along the old lines of weakness rather than in the production of new rifts. Proof, if such shall be found, that the veins are older than the joints, while not in itself conclusive, would render the torsional theory less objectionable, though even then the lack of any definite direction in their trend would be wellnigh fatal to any such conclusion.

Dr J. H. Pratt, on the other hand,* regards the vein cavities as primary. Noting that such occur only in those portions of the serpentine in close contact with the country rock, it is argued that they were produced by the more rapid cooling of these portions of the igneous magma, and have been "filled with serpentine deposited from aqueous solutions from their walls," the filling and crystallization in fibrous form having taken place "some time before the complete alteration of the primary rock into serpentine." With this view the present writer does not agree, since not only does he know of no instance in which an igneous rock has become cracked under the conditions described, but, further, these cracks and the fibrous serpentine are to be found among rocks which are not of igneous origin at all. In the case of the Montville, New Jersey, serpentine, for instance, the serpentine has been here shown † to originate through the hydration of a lime-magnesian pyroxene occurring in disseminated granules and nodules throughout a white crystalline granular dolomite. In this are reproduced all the characteristic phenomena of jointing, slickensided surfaces, platy and fibrous structures, but, as well, narrow veins of fibrous material (chrysotile), the veins being in a general way parallel to the surface of the original nodule of pyroxene. It is self-evident that in this case no cooling of an igneous mass can be considered as in any way effective, and almost equally evident that strains due to the movement of the material in mass also need no consideration.

The writer's own opinion, founded on the facts at present available, is that the crevices are due to shrinkage such as is incidental to the change of a highly hydrated, colloidal substance into a less hydrated and more solid form, and perhaps also to loss of silica, as suggested by Professor Kemp. In other words, he would compare them with the shrinkage cracks which appear in clay on drying, or, better yet, those which result from the shrinkage of a gelatinous mass of iron carbonate, as in the so-called septarian nodules of clay-iron stone (see plate 34). Such cracks resemble those of the serpentine in a striking manner, their disposition to widen toward the center and pinch out toward the margin being, in the case of the septarian, due to the spherical or oval form of the body—a condition of affairs that does not exist in the serpentine.

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* Mineral Resources of the United States, 1903. The exact wording is as follows:

"It can be conclusively shown in nearly all cases that the serpentine in which the chrysotile asbestos is found is of igneous origin. . . . The original rock in cooling would solidify first along its contact with the rocks through which it had penetrated and where it was in contact with any included masses of the country rock that had been broken off during the intrusion of the molten magma. The outer portions of the molten rock would thus cool much more suddenly than the interior portion, and there would be a tendency for them to develop cracks and parting planes. In the alteration of these primary rocks to serpentine, through the agency of aqueous solution, vapors, etcetera, there would be perhaps, to some extent at least, a widening of these cracks; but in the end they would be filled with serpentine deposited from aqueous solutions from their walls, and the resulting fibrous structure of the serpentine filling these seams represents the nearest approach to a true crystallization that the mineral serpentine assumes except when it is found as a pseudomorph after another mineral. It is probable that this chrysotile asbestos may have been formed some time before the complete alteration of the primary rock into serpentine. . . .

"A study of the occurrence of the chrysotile asbestos in the field shows that wherever commercial quantities of this asbestos are found they are in the serpentine and close to its contact with the surrounding country rock or adjacent to masses of the country rock that have been included in the serpentine. Farther away from these masses of gneiss or other country rock the chrysotile variety begins to give out. With very few exceptions, all the fibers of the asbestos are standing at nearly right angles to the sides of the seams, which would conclusively show that they were not formed by any shearing movements of the rocks."

† G. P. Merrill: Proc. U. S. Nat. Mus., vol. xi, 1888, pp. 105-112.

In putting forward this idea the writer realizes that he is complicating the commonly accepted ideas regarding serpentinization, since, as here outlined, it involves a process of hydration and swelling sufficient to produce the jointing and slickensiding and a shrinkage sufficient to produce the cracks, and this latter, too, while the rock contained a sufficient amount of moisture to carry the new material into the veins, where it crystallized.

Filling of the Vein Cavities

It is perhaps a question if both the formation and refilling of the fissures were not contemporaneous with and incidental to this process of dehydration and shrinkage. The assumption of a fibrous structure under quite similar conditions is sometimes seen in gypsum and more rarely in calcite. In the first named the crystallization apparently takes place by a process of growth from one of the walls, considerable force being manifested—sufficient, it may be, to rupture the rock mass in which it is taking place.* Whether or no such a condition of affairs exists in the case of the asbestos veins is perhaps yet to be proved. It is noted, however, that veins of any considerable width rarely show continuous fibers extending from side to side. In most cases the continuity is interrupted by small fragments of the wall rock; or, again, where this is lacking there exists at some intermediate point between the walls a break or line of separation as though the crystal fibers had been pushed outward from either wall until their extremities met. In many such cases the growth has continued until the fibers are pushed past one another to a slight extent, the line of contact thus becoming jagged or saw-like. Again, there are other indications of pressure from the direction of the walls, manifesting itself most frequently in a crimping of the fibers.

In brief, the views of the present writer are to the effect that the vein cavities are due to shrinkage and the vein filling to processes of crystallization, extending from either wall inward.

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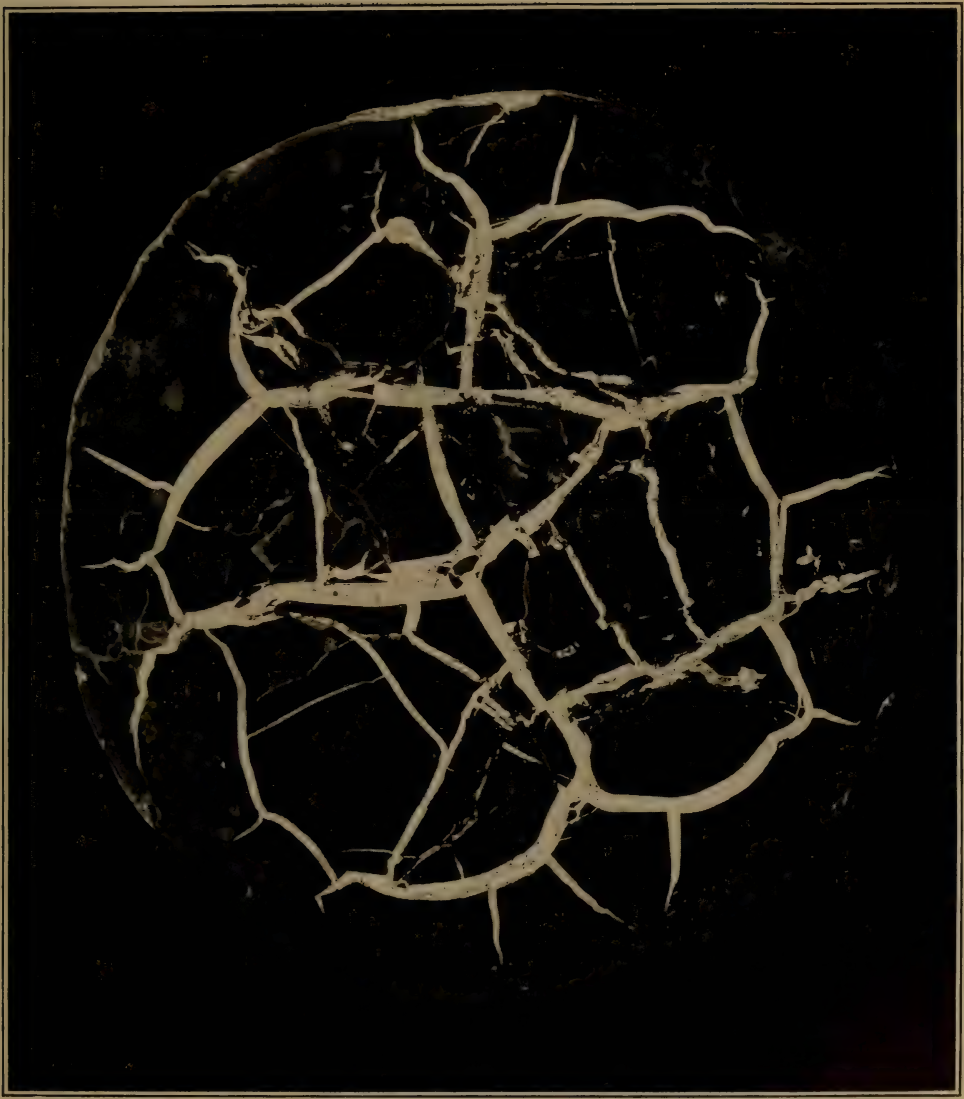
* G. P. Merrill: The formation of gypsum in caves. Proc. U. S. Nat. Mus., vol. xvii, 1894, p. 81.



SEPTARIAN NODULE OF CLAY-IRONSTONE

The veins shown are shrinkage cracks filled with calcite

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 16, PP. 137-150 MARCH 15, 1905

BEARING OF SOME NEW PALEONTOLOGIC FACTS ON NOMENCLATURE AND CLASSIFICATION OF SEDIMENTARY FORMATIONS

BY HENRY SHALER WILLIAMS

(*Read before the Society December 29, 1904*)

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SUMMARY OF WRITER'S VIEWS PREVIOUSLY EXPRESSED

It was suggested by the writer, in a paper read before the Geological Society in 1893,* that duality of nomenclature was desirable in order to discriminate between the divisions of the time scale and those of the formation scale, and later (1902–'3), when the revised rules of nomenclature and classification were being prepared by the United States Geological Survey,† it was still thought that the two scales might be discussed separately if only the criteria of discrimination and the nomenclature were kept strictly distinct. In 1903,‡ in a paper published in the Bulletin of this Society, the shifting of faunas during the continuance of their biological integrity was shown to be a fact, and it was pointed out that consequent precaution was necessary in using fossils with precision in classifying formations. In papers recently completed and now being published as Bulletin 244 of the United States Geological Survey the application of these principles and rules to certain specific cases is set forth in detail.

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*Journal of Geology, vol. 2, pp. 145-160.

†See Twenty-fourth Annual Report U. S. Geol. Survey, pp. 21-27.

‡See vol. 14, pp. 177-190.

Suggested Modification of Rule 14

In all these various papers the attempt was made to employ common nomenclature, as far as practicable, in describing the intricate relationships existing between the fossil faunas and the geological formations under discussion. While revising the proofsheets of Bulletin 244, however, the conviction became positive to the writer that one of the chief difficulties presented by this whole problem of classification and nomenclature of geologic formations arises from the very vague and uncertain use of the word "contemporaneity." In the revised "rules" referred to, although the word "contemporaneity" is dispensed with, the idea is still perpetuated in the phrase "chronologic equivalences." Rule 14 reads as follows:

> "The fundamental data of geologic history are (1) the local sequences of formations and (2) the chronologic equivalences of formations in different provinces. Through correlation all formations are referred to a general time scale, of which the units are periods. The formations made during a period are collectively designated a system."

The purpose of the present paper is to raise the question as to whether "chronologic equivalences of formations" are fundamental data of geologic history, and, if not, whether the "fundamental data" indicated by that expression are not in reality the similarities in the fossil faunas of formations of different provinces. In practice is it not also true that formations are not referred to a "general time scale," but to a stratigraphic scale, of which not "periods," but systems, are the units? Considering these queries as answered in the affirmative, why should not rule 14 read as follows:

The fundamental data of geologic history are (1) the local sequences of formations and (2) the similarity of the fossil faunas of the formations of different provinces. Through correlation all formations are referred to a standard stratigraphic scale, of which the units are systems.

Views of Huxley and Geikie

Before discussing the facts of the particular case or bearing on this proposition, the exact point in issue may be emphasized by referring to the argument used by Huxley in 1862 for the substitution of "homataxis" for "contemporaneity."

Huxley,* in his anniversary address before the Geological Society of London in 1862, said:

> "Paleontology has established two laws of inestimable importance: The first, that one and the same area of the earth's surface has been successively occupied by very different kinds of living beings; the second, that the order of succession established in one locality holds good, approximately, in all. . . . As a consequence of the second law, it follows that a peculiar relation frequently subsists between series of strata, containing organic remains, in different localities. The series resemble one another, not only in virtue of a general resemblance of the organic remains in the two, but also in virtue of a resemblance in the order and character of the serial succession in each. There is a resemblance of arrangement; so that the separate terms of each series, as well as the whole series, exhibit a correspondence. Succession implies time; the lower members of a series of sedimentary rocks are certainly older than the upper; and when the notion of age was once introduced as the equivalent of succession, it was no wonder that correspondence in succession came to be looked upon as correspondence in age, or 'contemporaneity.' And, indeed, so long as relative age only is spoken of, correspondence in succession is correspondence in age; it is relative contemporaneity. But it would have been better for geology if so loose and ambiguous a word as 'contemporaneous' had been excluded from her terminology, and if, in its stead, some term expressing similarity of serial relation, and excluding the notion of time altogether, had been employed to denote correspondence in position in two or more series of strata. In anatomy, where such correspondence of position has constantly to be spoken of, it is denoted by the word 'homology,' and its derivatives; and for geology (which, after all, is only the anatomy and physiology of the earth), it might be well to invent some single word, such as 'homotaxis' (similarity of order), in order to express an essentially similar idea."

Huxley further called attention to the fact that it is generally admitted by all the best authorities

> "that neither similarity of mineral composition, nor of physical character, nor even direct continuity of stratum, are absolute proofs of the synchronism of even approximated sedimentary strata; while for distant deposits, there seems to be no kind of physical evidence attainable of a nature competent to decide whether such deposits were formed simultaneously, or whether they possess any given difference of antiquity.†
>
> "Edward Forbes was in the habit of insisting that the similarity of the organic contents of distant formations was *prima facie* evidence, not of their similarity, but of their difference of age."‡

His conclusion was that

> "There seems, then, no escape from the admission that neither physical geology nor paleontology possesses any method by which the absolute synchronism of two strata can be demonstrated. . . . For areas of moderate extent it is

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*Q. G. G. S., London, vol. xviii, p. xli.

† Loc. cit., p. xliv.

‡ Loc. cit., p. xlv.

doubtless true that no practical evil is likely to result from assuming the corresponding beds to be synchronous or strictly contemporaneous, and there are multitudes of accessory circumstances which may fully justify the assumption of such synchrony. But the moment the geologist has to deal with large areas or with completely separated deposits, then the mischief of confounding that 'homotaxis,' or 'similarity of arrangement,' which can be demonstrated, with 'synchrony,' or 'identity of date,' for which there is not a shadow of proof, under the one common term of 'contemporaneity' becomes incalculable and proves the constant source of gratuitous speculations." *

Discussing this same problem, Geikie † says:

> "Strict contemporaneity can not be asserted of any strata merely on the ground of similarity or identity of fossils."

ILLUSTRATIONS OF IMPORTANCE OF STRATIGRAPHIC RATHER THAN TIME BASIS

IN GENERAL

In the bulletin (number 244) referred to two or three particular cases are elaborated which exhibit the importance of using a purely stratigraphic basis in discussing the relations of faunas to formations and of freeing the definition of formations from all time designations. The geologist is referred to the bulletin for details. Only the main facts will be here mentioned. The three cases to which attention is called are as follows:

MONTEREY, ROMNEY, AND JENNINGS BEDS OF VIRGINIA AND WEST VIRGINIA

First, the faunal combinations and successions in numerous sections cutting through the beds called Monterey, Romney, and Jennings, in Virginia and West Virginia, were analyzed. The facts developed show that at the base of the beds called Romney occasionally a few fossils of the Corniferous and Hamilton of New York, but thereafter the Marcellus, Genesee, and Portage (New York), faunas dominate, to be followed above by Chemung types in cases where these latter are not altogether wanting. In the cases where the Hamilton species appear they are associated with Corniferous forms and lie below the typical black shales called Romney (in Virginia), a formation reported to be the equivalent of the Hamilton and Marcellus.

CATAWISSA SECTION OF PENNSYLVANIA

The second case is that of the Catawissa section, in central Pennsylvania. After passing above beds which faunally and lithologically are correlated with the Genesee shales, the beds following, for 1,200 feet, are found to be dominated by an Ithaca fauna. This shows an extreme, so far met with, of the limit of expansion of that fauna.

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* Loc. cit., p. xlvi.

† A. Geikie: Text Book of Geology, second edition, 1885, p. 608.

DEVONIAN SECTION OF GENESEE VALLEY, NEW YORK

In the third case—the section of the Devonian in the Genesee valley, New York—the Ithaca fauna is entirely wanting, and is there replaced by the Buchiola fauna of the Cashaqua, Gardeau, and Nunda ("Portage") formations. In the Seneca Lake valley a slight trace of the Ithaca fauna is seen above the Sherburne, but only slight. The Sherburne, with its Buchiola fauna, is followed by the Ithaca (400 feet), containing a rich and characteristic fauna, which is then followed by 600 feet of Enfield shales, in which the Buchiola fauna again returns with some modifications.

GENERAL DISCUSSION OF THE THREE TYPICAL ILLUSTRATIONS

The case of the Catawissa section, in which the Ithaca fauna occupies an interval of nearly 1,500 feet, wherever fossils occur, is a striking illustration of local difference in range of faunas, since the great thickness of sediments through which the Ithaca fauna ranges can not be interpreted as increase in thickness of sediments of that particular part of the section, for the sequence of faunules is in its normal order from Genesee to Chemung, but the Ithaca fauna (which is entirely wanting in the Genesee section), there dominates over all associated faunas from near the base to the top of the fossiliferous zone.

The real problem before us may be presented by considering the first case in detail. The chief facts are as follows: In New York there is a standard set of formations occupying a particular portion of the geological column, with which we are all familiar. The formations and their relative positions in the stratigraphic scale are Oriskany, Corniferous, Marcellus, Hamilton, Genesee, ("Portage" or) Nunda, Chemung, and Catskill, together constituting the main part of the Devonian system of that province.

The United States Geological Survey geologic folios for Virginia and West Virginia (take, as examples, the Stanton, Franklin, and Monterey quadrangles) present the same portion of the geological column, divided on a stratigraphic basis into the Monterey, Romney, Jennings, and Hampshire formations.

In the text of the Stanton folio equivalence is implied by a table in which the divisions of the scale, with the names and symbols used in the folio, are (in an adjoining column) filled with names which have been used by various authors, as follows:

Dh	Hampshire formations	Catskill.
Dj	Jennings formations	Chemung.
Dr	Romney shale	Hamilton.
M	Monterey sandstone	Oriskany.

This folio was published in 1894. The Franklin folio, published two years later (1896), included the statement that "the implied correlations with other stratigraphic areas are not necessarily accepted," and under Monterey, in the text, "the fossil remains in this formation are in greater part those which are typical of the Oriskany formation of New York. Under Romney shale, in the same text, appears the statement "the Romney shale contains fossils, including species distinctive of the Hamilton group; those in the lowest beds comprise some species characteristic of the Marcellus," and under Jennings formation "fossils occur in various beds in the Jennings formation and represent the Chemung fauna."

In volume I of the Maryland survey (page 182) "four divisions are recognized in the sequence of Devonian deposits, known as the Monterey, Romney, Jennings, and Hampshire formations."

The inexact nature of this equivalence is indicated in the more detailed "Report for Allegany County, Maryland," in which the old name Oriskany is adopted for the first divisions, and the Romney formation is described as "corresponding in the main with the Marcellus and Hamilton formations farther north" (page 103). The Jennings formation is described as "closely related to the Chemung and Portage of the Pennsylvania and the New York Geological Surveys" (page 106), and the Hampshire formation is said to be "approximately equivalent to the Catskill of the north" (see page 108).

In the case of the Romney formations a twofold paleontological division of the formations is already claimed by Prosser.* It is evident that the classification and nomenclature adopted in the earlier studies of these formations is based on a general homotaxial equivalence and not upon either exact lithologic or paleontologic likeness of the formations or their contents. A more minute examination of the fossil contents demonstrates a lack of parallelism, as is shown by Prosser's paper on the Maryland section and by my Bulletin 244 for the sections farther south in Virginia, West Virginia, Kentucky, and Indiana.

We are therefore obliged to question the propriety of calling the formations of the central Appalachian area, namely, Romney, Jennings, and Hampshire, as "exact synonyms" of Hamilton, Chemung, and Catskill.† In the case in question the facts seem to be established that a general similarity in the sequence of sediments * can be clearly recognized between the sections of Maryland and Virginia and those in the New York and Pennsylvania area of the Devonian.

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*Journal of Geology, vol. xii, 1904, pp. 361-372.

†See Bulletin 191, U. S. Geol. Survey, pp. 351, 211, and 186.

If lines are drawn across the sections in New York state corresponding to the more strongly marked lines of separation between different types of this sedimentation, they serve to divide off a set of standard formations, and the fossils of these formations have been tabulated to constitute the faunas of the formations so established. Thus the Corniferous, Marcellus, Hamilton, etcetera, are established as standard formations. Passing a few hundred miles to the southward, to Virginia, similar lines may be drawn across the same general series of Devonian sediments to make three divisions corresponding in a general way with the more striking divisions of the New York section; but they do not agree in detail, in thickness, or in fossil contents. While, therefore, it may be convenient to speak of them as occupying the same general place in stratigraphic succession with the New York formations indicated as correlated with them, the differences in all of their visible characters are sufficient to forbid calling them the same formations, or even chronologic equivalents.

ANALYSIS OF THE FAUNAS

The analysis of the faunules, as gathered in Bulletin 244, shows that the fossil faunas contained in the strata classified in the folios as Romney, Jennings, and Hampshire are not the same as those of the New York formations with which they are compared, namely, the rocks belonging to the part of the column called Romney, in central and southern Virginia, contain chiefly the faunas found in New York in the Marcellus, Genesee, and Nunda (" Portage "), with only traces of the Hamilton fauna near their base. The Jennings formation does, in many cases, hold a " Chemung fauna ; " but as it is followed southward along the Appalachian this latter fauna is lacking, and the succession is then directly from the black Romney shales upward into a Mississippian, or lower Carboniferous, fauna, occurring in the shales after the black shale sediments ceased, while the fauna of the Genesee-Portage formations of New York chiefly fills the lower interval. The evidence indicates that when the specific Hamilton, Ithaca, and Chemung faunas are wanting in the sediments of the middle Appalachian region a fauna of the type (found intercalated between them in the New York area) seen in the Marcellus, Genesee, and Nunda (" Portage ") of New York, dominates throughout that portion of the sections where the former faunas are expected.

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* Passing from limestone through black shales, fine and evenly laminated; then coarser, thin bedded, argillaceous shales and sandstones; next sandstones of thicker and more frequent occurrence, running into coarser cross-bedded sandstone with red beds occasionally interspersed, and finally coarser sandstones with occasional conglomerates.

This interpretation of the facts is associated with other evidence pointing to no unconformity or culling out of parts of the stratigraphic series, but rather to a continuous, uninterrupted sedimentation, in which the fossils so prominent at several particular horizons in New York are actually wanting, and their place in the stratigraphic series is occupied by other faunas, which in New York occupy intermediate positions.

INTERPRETATIONS AND CONCLUSIONS

Thus, if we interpret like faunas into equivalence of formation we are obliged to say that in central and southern Virginia the Genesee and Portage faunas range through the main part of the Romney and part of the Jennings formations, and the Jennings holds a pure Chemung fauna only in its upper or central part; but in no case do the fossil contents give a basis for saying that the Romney is the exact equivalent of the Hamilton or Marcellus, or both, nor that the Jennings is the exact equivalent of the Chemung, when by equivalence is meant the same fauna or fossil contents. Equivalence is therefore a correct term to apply to the formation names united by a hyphen only when the inference is drawn that the beds were deposited at the same period of time (contemporaneity), since the lithology, stratigraphy, and fossils are all diverse for each couplet. Therefore it can not be claimed that there is either lithologic, stratigraphic, or paleontologic equivalence. Of course, it is to be expected that at any particular epoch of geologic time in different regions of the earth formations were being made which present no agreement in lithology or in fossils; but when we come to deal with such formations as geologic units, define them in scientific terms, and represent their outcrops on geologic maps, it is all-important to restrict the terms of definition to observable facts, and to classify and name formations as the same only when the terms of their definition agree. In the case before us the terms of definition disagree. This fact alone is sufficient reason for applying different names to the stratigraphic divisions in Virginia (Romney, Jennings, and Hampshire) which are correlated in a general way with divisions called Marcellus, Hamilton, Chemung, etcetera, in New York. It also follows from what has been said that equivalence, when used in a chronologic sense, may or may not mean equivalence of all or any of the criteria used in defining the formation. A formation may be said to be equivalent in the chronologic sense (that is, formed at the same time) when the lithology and paleontology are entirely discordant, and it may be true, but the evidence of the truth of the statement is complex and not discernible by simple examination of the formations themselves. It is on account of this complexity of the proofs and the varying opinions as to both the value and the inferences regarding contemporaneity to be drawn from any or all the visible evidence supplied by the formations as geologic units that leads me to a conviction that we must dispense with any association of time with the definition of a stratigraphic formation, and use, in discriminating, defining, and classifying them, only those marks which are visible and can be measured, located, and described in scientific terms.

In all such cases as in the one cited the facts are stated, when it is said that correlation with the Devonian system is recognized in the Virginia formations, Monterey, Romney, Jennings, and Hampshire, that their division is recognized in the Virginia region on a basis of lithologic difference, and that the homotaxial relations of these formations, roughly speaking, correspond to the Oriskany, Hamilton, Chemung, and Catskill of the New York classification. It is misleading, however, to speak of the several pairs of formations as "chronologic equivalents." The evidence is not in hand to prove that they are or are not; their chronologic relations are still to be established.

If any of the fossils occurring in the Hamilton formation, as defined in central New York, were strictly confined in their vertical range to the limits marking the base and the top of the portion of the section described as Hamilton, the case would be different. In such a case it would be possible to infer that the same fossils elsewhere could be interpreted into contemporaneity of sedimentation. But the facts accumulated disprove such an assumption; and until the total stratigraphic range for fossils is ascertained for each area of distribution, and the question as to whether that range is different in separate regions is established, fossils can not be used as proof of the contemporaneity of short sections of the stratigraphic column which happen locally to hold the same species.

Geological Usage of Term Fauna

A word may be added to explain the geological usage of the term fauna.

In literature there has grown up from the old conception of separate creations and the peopling of the earth with separate organism at the beginning of each geological period the idea that the fossils found in a formation are peculiar to the formation—are "leit fossilien." Thus the time when a formation was formed and the fossils contained in the formation have come to be regarded as correlative terms. The time scale is thus regarded as only another mode of indicating the stratigraphic scale. This conception is fully elaborated in the early reports of the International Geological Congress, and the divisions of the time scale—" era," " period," " epoch," " age "—are there regarded as strict equivalents of " group," " system," " series," "stage," so far as their application to the facts of stratigraphy is concerned.

Most geologists, having been accustomed to use these terms as interchangeable, may find difficulty in recognizing the bondage to old ideas which this usage enforces.

Although the American geologists have adopted another system of nomenclature, the influence of this implication is still apparent in the confusion of chronologic language with physical facts. To avoid this confusion the writer began several years ago to classify fossils into faunas, irrespective of the formational limits to which they were supposed to be restricted, and the fact has clearly developed that formational limits do not by any means mark the range of either the fossils of a formation or of the integrity of associations of species into groups of faunas. Thus the fact has developed that the local formation which in a local section contains a diagnostic fauna is limited below and above, not by the beginning and ending of the life history of the particular fauna, but only by the beginning and ending of the fauna of the particular locality where the sedimentation took place. In another locality, it may be not far distant, the same fauna may appear at a lower or higher stratigraphic horizon and in its integrity. It may also reappear in the same locality after having been entirely absent from the sediments for a period of time represented by hundreds or thousands of feet of sediments, and in such cases the fauna is more apt to show disturbance of its contents than when the whole fauna has become shifted. This explanation will make it clear why the presence of a species of the Hamilton fauna in the Romney of Maryland, Virginia, Kentucky, or Indiana does not furnish proof of the Hamilton period, epoch, or even formation, as those terms are used in current literature.

The fossils of the Hamilton formations of New York undoubtedly have a definite stratigraphic range, which we may hope to determine in the future, but that will not change the stratigraphic limits of that formation. It will, however, enlarge the chronologic limits expressed by the fauna of the Hamilton formation. The facts already in hand show that the New York Marcellus below and the Nunda (" Portage ") and part of the Chemung formations above are included in the time period through which the Hamilton fauna ranges. In order to distinguish the names of these two units the fauna of the Hamilton formation of New York is called the Tropidoleptus fauna.

While it is practicable to establish homotaxial equivalence between a particular local fauna and the general fauna of some particular system (and perhaps to locate the fauna in its lower, middle, or upper portion), it does not follow that a closer degree of equivalence can be established between two local faunas by the same criteria. In the first case the general equivalence may be proven in a case in which few or none of the species are identical species, but even in case the identity of species in two formations is proven, the equivalence so established is only within the limits of the known range of the species of the fauna. This range in most known cases is at least as much as a third of the thickness of the system in which it belongs. We are therefore forced to the conviction that in the correlation of local formations the same species of fossils alone (when so much as 50 miles of distance separates their stations) can not be relied on for establishing more than a general homotaxial relation of the formations compared. The limit of range of every species is far greater, both above and below, than is indicated by any local formation in which it occurs. Geologists have already recognized the fact that uniform conditions of sedimentation are local as well as temporary, and the same principle must be applied to fossils. The vertical range of individual species, as well as that of their combination into faunules, varies greatly with the local conditions that prevailed during the life of the species, and thus their place in the vertical stratigraphic column varies with geographic distribution.

Summary and Conclusions

What has been said refers to the geologic formation as a particular mass of stratified rocks occupying a particular position or horizon in the geological column and whose geographical extent may be determined. What I am urging is that greater clearness of description and accuracy of statement will be attained in describing such formations if all reference to time relations be dispensed with. Let us speak of them as "homotaxial;" but when their lithologic or paleontologic characters differ, let us say so and call the formations by different names and indicate their general relations to the standard scale simply by bracketing them as Devonian, or, if the correlation be more definite, as Eodevonian or Mesodevonian, as the case may be, but not as the equivalent of a formation which we regard as formationally distinct.

The next point I have to make is that in the definition, and particularly in the mapping, of formations it is important to make the definition so that the mass not only can be located and recognized by the terms of the definition, but so that its limits can be distinctly recognized in the field. In the examples selected the line between the Romney and Jennings and that between Jennings and Hampshire are frankly described in the folios as so indefinite as to be recognized with difficulty. Geologists are not always so frank on this point when they return from the field. The evidence brought forward by the analysis of the faunas shows that if the lithologic transitions are perplexing in the case in question the sequence of faunules is also unsatisfactory for establishing precise lines of separation between two contiguous formations.

In the course of the present investigations the recurrence of faunules has become an established fact, and not only for a short vertical distance through the beds, but recurrences of faunules of the same fauna have been traced for a thickness of hundreds and in one region up to about 2,000 feet of sediments in which intercalation of entirely distinct faunas has taken place. With these facts in view, we are deceiving ourselves when we presume that half a dozen fossils of particular species occurring together determine the stratigraphic horizon, so that the local line below or above them may always serve for the limits of the formation. The fossils do indicate a general portion of the geologic column, but it is only indefinitely, somewhere within one or two thousand feet of thickness of strata. They do not alone establish equivalence of formation, when by formation is meant a definite part of the stratigraphic column set off by definite boundaries below and above.

It may also be stated that the sharper the paleontologic transition from one fauna to another (in ascending through a series of strata) the stronger is the certainty that the local limit thus assigned is not the stratigraphic equivalent of a similar sharp transition between the same two faunas elsewhere. The very fact of the definiteness of the faunas is also sure evidence that they had lived a long time before the first trace of them in the section and lived a long time after the highest traces in the local section, and the sharpness of the transition from the one to the other is evidence that the superior fauna was not derived from the lower one, but that the local succession is a result of movement and replacement of the faunas themselves.

The conclusion of the matter to which the facts force us is that not only lithologic but paleontologic facts are local. The fossil contents may completely change, often very rapidly and often in a few miles. The fossils undoubtedly are the means on which we chiefly rely for determining that kind of equivalence which is called contemporaneity and homotaxy; but it must not be overlooked that the characters of fossils (that is, the marks by which species and genera are distinguished) are extremely long ranging. Fossil species were not ephemeral things which changed every few feet of thickness of sediments.

In the use of fossils, for determining the geologic horizon of the formations containing them, the essential fact open to investigation is the presence or absence of the fossils themselves. The presence of individual fossils indicates, not some narrowly limited horizon, but a general portion of the stratigraphic scale represented by the system or by a large subdivision of it. By close discrimination characters of narrower vertical range can be detected, but up to the present time very few characters of fossils are known whose vertical range-limits are so narrow as to indicate an horizon of less than about a third of a standard system.

Certain modifications of current usage are suggested by the facts here presented, which may be expressed by the following recommendations:

In seeking to perfect the rules governing nomenclature and classification of sedimentary geologic formations should not the following principles be applied:

1. The abolition from the nomenclature, definition, and classification of geologic sedimentary formations of all reference to time or time relations.

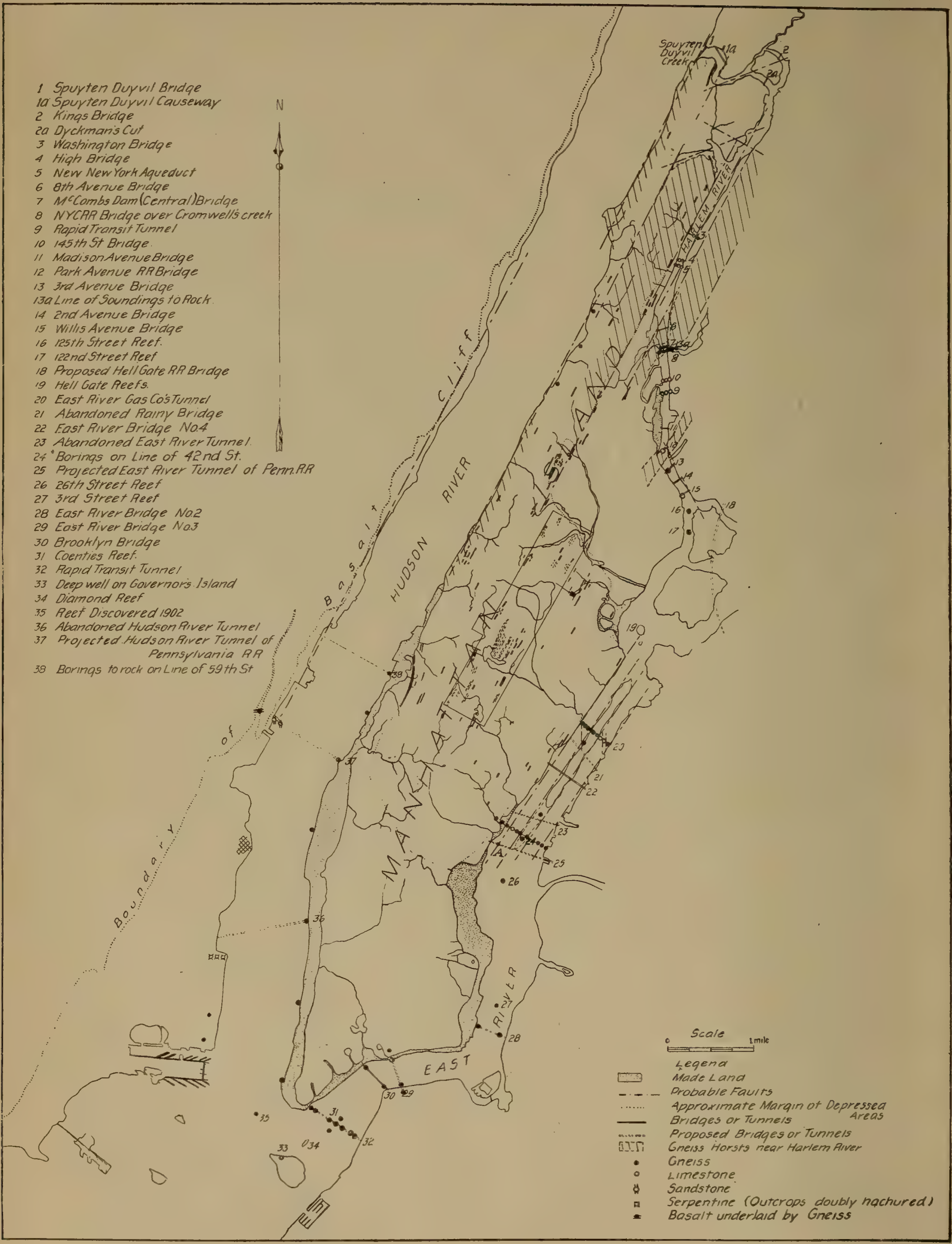
The application of this rule would result in the rewording of rule 14 of the " Revised Rules," as suggested at the opening of this paper.

2. The adoption of lithologic characters, stratigraphic position, and paleontologic contents as three (at least) chief means for discriminating and defining sedimentary formations.

3. The revision of technical nomenclature in the following particulars: In the place of time scale use the term stratigraphic scale; in place of contemporaneity use homotaxy; in place of age, in its general sense, apply the term horizon with the definite and technical meaning of position in the vertical stratigraphic scale; in place of period use the term system; it has already become common practice to speak of group, series, and formation on this general principle; in the place of earlier or older adopt the terms inferior, lower, subjacent, or underlying; in place of younger or later adopt the terms superior, superjacent, overlying; and in general in the selection of descriptive terms to apply to sedimentary formations, both in definition and correlation, employ physical characters (such as composition, texture, structure), special dimensions, and position in a vertical stratigraphic column in place of any chronologic terms, these latter, so far as formations are concerned, being inferential, not observable, and incapable of accurate application on account of the wide divergence of opinion as to the modes of their determination.

In proposing these changes in usage it should be stated that it is not intended in any sense to exclude the consideration of time relations in geological discussions, but rather to remove from the definition and discrimination of formations any reference to their *supposed* time relations in order that actual history and time relations in geologic history may be studied with a greater precision and freed from that vague prejudgment which naturally arises from confusing chronologic with physical and spacial ideas.

It may be mentioned further that in the discussion of fossils, faunas, and faunules time relations must be considered, since heredity and evolution are time questions; but for such discussions the formations and their exact position in a stratigraphic scale must be first established, independently of the fossils they contain, before the historical relations of the fossil faunas can be accurately discriminated. In the same way that physical geography must stand on a basis of physical definition entirely independent of political boundaries or political characters, so must formational geology derive its definitions, terminology, and classification from the characters which are actually possessed by formations and which can be examined, measured, and defined before the history of the organisms preserved in them can be accurately determined and before questions of the absolute time relations of geologic events can be established on a firm basis of fact.


1 Spuyten Duyvil Bridge
1a Spuyten Duyvil Causeway
2 Kings Bridge
2a Dyckman's Cut
3 Washington Bridge
4 High Bridge
5 New New York Aqueduct
6 8th Avenue Bridge
7 McCombs Dam (Central) Bridge
8 NYCRR Bridge over Cromwell's creek
9 Rapid Transit Tunnel
10 145th St Bridge
11 Madison Avenue Bridge
12 Park Avenue RR Bridge
13 3rd Avenue Bridge
13a Line of Soundings to Rock
14 2nd Avenue Bridge
15 Willis Avenue Bridge
16 125th Street Reef
17 122nd Street Reef
18 Proposed Hell Gate RR Bridge
19 Hell Gate Reefs
20 East River Gas Co's Tunnel
21 Abandoned Rainy Bridge
22 East River Bridge No 4
23 Abandoned East River Tunnel
24 Borings on Line of 42nd St.
25 Projected East River Tunnel of Penn. RR
26 26th Street Reef
27 3rd Street Reef
28 East River Bridge No 2
29 East River Bridge No 3
30 Brooklyn Bridge
31 Coenties Reef
32 Rapid Transit Tunnel
33 Deep well on Governor's Island
34 Diamond Reef
35 Reef Discovered 1902
36 Abandoned Hudson River Tunnel
37 Projected Hudson River Tunnel of Pennsylvania RR
38 Borings to rock on Line of 59th St
N
Spuyten Duyvil Creek
HARLEM RIVER
HUDSON RIVER
Boundary of Basalt Cliff
MANHATTAN
EAST RIVER
A
Scale
0
1 mile
Legend
Made Land
Probable Faults
Approximate Margin of Depressed Areas
Bridges or Tunnels
Proposed Bridges or Tunnels
Gneiss Horsts near Harlem River
Gneiss
Limestone
Sandstone
Serpentine (Outcrops doubly hachured)
Basalt underlaid by Gneiss

SKETCH MAP OF MANHATTAN ISLAND

Showing its hydrography, the location of some of the river sections, and the distribution of dikes (the last named after Julien).

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ORIGIN OF THE CHANNELS SURROUNDING MANHATTAN ISLAND, NEW YORK*

BY WILLIAM HERBERT HOBBS

(*Read before the Society December 31, 1902*)

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* This paper was read December 31, 1902, at the Washington meeting, and is mentioned on page 543 of volume 14, under title "Configuration of the rock floor of the vicinity of New York."

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Introduction

The engineering work recently completed and that now undertaken in and about the city of New York make it easily the focus for such enterprises on the planet—enterprises the cost of which must be estimated in the hundreds of millions. To mention but a few, there are the subway and the tunnels of the Rapid Transit railway, the East River bridges numbers 2, 3, and 4, the proposed tunnels of the Pennsylvania Railroad Company from Weehawken to Long Island City beneath the two rivers and Manhattan island, the completion of the old Hudson River tunnel from Jersey City to New York, and the dredging of the Buttermilk and Ambrose channels and of the Man-o'-War and Diamond reefs by the United States government. These are some of the larger of the recent enterprises. Of earlier ones, the government work in making the channel of Hell Gate by removing Flood and Mill rocks, the construction of the Croton and the new New York aqueducts, Dyckmans cut in the ship canal at Kings bridge, the East River Gas Company's tunnel from New York to Long Island City beneath Blackwells island, and the numerous bridges spanning the Harlem river, have all facilitated the work of the geologist within the New York city area. Taken together, they have furnished more than 35 sections crossing the rivers forming the water front of the island, many of them revealing the nature of the subjacent rock, and not a few giving practically complete sections across it.

The present is, then, an especially favorable time to study the geology of the channels, and it is of great importance that observations be now made and recorded, lest the opportunity be forever lost.

Theories of Origin of the New York Water Front

The unexcelled harbor facilities of New York city have furnished a fascinating subject for study, and writings of geologists on the structure of Manhattan island have devoted considerable space to it. As is well known, the water-courses surrounding the island form sharply incised tideways of quite exceptional depth. Stevens accounted for the location of the lower Hudson, the Harlem, and the East rivers both by the position of supposed belts of limestone and by longitudinal faults along the channels.*

Dana ascribed their formation entirely to the presence of supposed limestone belts, and formulated the theory which has since formed the subject of many papers; all, so far as is known, in support of the theory, although comparatively little evidence has been adduced for it. Dana stated his views as follows: †

> "From the distribution of the limestone, as exhibited on the map, and the fact of its easy wear or erosion, we derive explanations of several topographic features of New York island and the adjoining region. For example, we learn—
>
> Why Harlem river has its present position and depth, and its north and south course; why there is an 'Eighth Avenue valley;' why the 'Inwood parade grounds' are a broad rolling region from the Harlem to the Kings Bridge road; why, south of the Inwood Presbyterian church, there was a Kings Bridge road valley, to fix the position of that old highway; why Shermans creek bends around the Fort George heights; why Cromwells creek exists and the valley or 'Clove' to the north; why Fleetwood park is low and nearly flat, except its western side; why Third avenue in Harlem and the region east of it is low; why wide flats (with small exceptions) extend from East river more than two-thirds of the way across the island, just north of Central park, and, perhaps, why there is an East River channel."

An objection to the full acceptance of his theory led him to add:

> "The limestone lands that are not low may owe their height to the fact that erosion follows water-courses; but, besides, the rock when in nearly vertical beds—usually the fact in such places—is generally of a firmer kind, because the pressure which gave the beds this position, served to compact the rock and so favored closer and better consolidation."

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* History of the geology of New York island Ann. Lyc. Nat. Hist. N. Y., vol. viii, 1865, pp. 108-120.

† J. D. Dana: Geological relations of the limestone belts of Westchester county, New York. southern Westchester county, and northern New York island. Am. Jour. Sci. (3), vol. xxi, 1881, pp, 25-443; also ibid., vol. xxii, 1881, pp. 313-315.

Newberry had earlier (1878)* offered a partial theory in assuming the East river to be the old course of the Housatonic, and the Harlem and Spuyten Duyvil Creek tributary streams. Such an explanation, however, fails to cover the exact location of these courses, which was the point aimed at by Dana. Professor Kemp in his paper on the Geology of Manhattan island † accepts Dana's view, but adds that the course of the Harlem river east of the McCombs dam requires another explanation, and suggests that as its course below that point corresponds very closely to the direction of the glacial scratches, the river may have been directed by the glaciation. In a brief note on the Blackwells Island tunnel ‡ he has extended the theory to include the eastern channels, which was merely suggested by Dana, and has quoted Dr F. J. H. Merrill in support of this view. Later Merrill and Kemp have each elsewhere published the same explanation.§ Gratacap, || in his recent pamphlet on the Geology of New York, refers to the view of Stevens that the Hudson river is underlaid by limestone, and adds that it is an extremely unlikely supposition. In the recently published New York city folio Willis ¶ apparently ascribes the direction of the lower course of the Hudson to the location of weaker beds along its channel, though he adds that this explanation may be modified by the existence of faults. He says:

> "It [the Hudson river] had had a complex history, dating back to the Schooley plain (upon which it probably began its course across the highlands), involving adjustment to belts of weak rock, such as dolomite and arkose, and possibly including effects of that faulting which has been described as traversing the Newark rocks and of which there is some evidence in the physiographic relations of Staten island. All that early history of the river awaits elucidation."

Regarding the area east of the Hudson, Willis says:

> "It probably happened that originally the rivers of the area had other courses indifferently across the dolomite, schist, and gneiss, but such is the manner of growth of streams and valleys that, though they were once so situated, the larger ones must have become rearranged in precise adjustment to the lines of weak rock. . . . Adjustment of valleys to belts of easily eroded rocks is a condition which is reached only through prolonged competition among growing river systems, and when it is so perfectly accomplished as it is east of the Hudson, it indicates that the streams have been long at work carving this intricate mosaic of rock masses."

---

* J. S. Newberry: Geological history of New York island and harbor. Pop. Sci. Month., vol. xiii, 1878, pp. 641–660.

† Trans. New York Acad. Sci., vol. vii, 1887, p. 61.

‡ J. F. Kemp: The geological section of the East river at Seventieth street, New York. Trans. New York Acad. Sci., vol. xiv, 1895, pp. 273–276.

§ F. J. H. Merrill: The geology of Greater New York. Trans. New York Acad. Sci., vol. xvi, 1897, p. 371.

J. F. Kemp: Trans. Am. Soc. Civ. Eng., vol. xxxix, 1898, pp. 79–80.

|| L. P. Gratacap: Op. cit., p. 39.

¶ New York city folio, p. 17, first and fourth columns.

Merrill in the same folio[*] has carried the theory to its extreme. Not only are the windings of Spuyten Duyvil creek and the Harlem river supposed to follow the course of a belt of limestone, but even Long Island sound near New York is supposed to have the same origin. These assumptions are based largely on the " white residuum " obtained from dredgings by the dock department.[†]

If we grant that this white material may be the residual product from the solution of dolomite, its presence at the bottom of a swift tideway like that of the East and Harlem rivers can have but little significance, when it is remembered that the Harlem flows between limestone walls for a considerable portion of its course.

In a recent extended report on the Glacial and post-Glacial history of the Hudson valley, Peet[‡] has favored the view that the Hudson water front was in post-Glacial time a lake impounded by a moraine, the inlet now existing through the moraine having been formed by the cutting down of the lake outlet so as to form the present Narrows. He says:

> "In conclusion, it may be stated that while no single argument seems to be fatal to the salt-water hypothesis accounting for the Hudson water body, unless those drawn from the phenomena on the outside of the moraine be such, it is likewise true that the facts are not fatal to the lake hypothesis, unless the sponge spicules reported from Croton represent salt-water species. Aside from these sponge spicules, the weight of the evidence seems to be in favor of the lake hypothesis."

Julien, in discussing the faults on the island, has called attention to the evidence of the transverse fracturing of the rock at Spuyten Duyvil creek:

> "At other localities, as, for example, at the huge pit on Spuyten Duyvil creek, portions of the hornblendic rock are traversed by innumerable veinlets of quartz or pegmatite, indicating a shattered or even brecciated mass."

FORM OF THE ROCK FLOOR BENEATH THE NEW YORK WATER FRONT

GENERALLY ACCEPTED VIEW

From the above review it will appear how generally Dana's theory has been accepted and also how little evidence for it has been adduced. It has come to represent, however, a body of opinion to some extent inherited, and it probably owes its favorable acceptance largely to the fact that the principal channels about New York island trend approximately with the general strike of the rocks, as it does also to the known occurrence of limestone at the bottom of the Harlem gorge. To the writer it has seemed that there is a general tendency among geologists to overestimate the importance of limestone belts in conditioning the location of valleys and low areas in the topography. The exceptional opportunity for testing this theory in the New York city area by reason of the numerous artificial sections across the river channels presented itself to him in the season of 1901, when considerable study was made of the area. It is perhaps true that nowhere in the world could the general problem be investigated under more favorable conditions. The inquiry begun nearly four years ago has been prosecuted since as opportunity has offered, until data gathered are about as comprehensive as they can well be made now, though they are likely to be somewhat augmented in the future.

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[*] Op. cit., p. 4, columns 3 and 4.

[†] Merrill: Op. cit., p. 4. See also F. J. H. Merrill and D. S. Martin: Note on the colored clays recently exposed in railroad cuttings near Morrisania, New York. Trans. New York Acad. Sci., vol. ix, 1889, pp. 45-46.

[‡] Charles Emerson Peet: Glacial and post-Glacial history of the Hudson and Champlain valleys. Jour. Geol., vol. xii, 1904, pp. 415–469, 617–660.

As already stated, the generally accepted hypothesis assumes that the channels of the Hudson and East rivers and the sinuous course of the Spuyten Duyvil and the Harlem, are alike underlaid by limestone, even where gneiss forms the wall rock on either side. This latter difficulty Merrill has sought to explain for the Spuyten Duyvil locality by assuming a sudden and steep pitch to the southward of the northern gneiss mass (Fordham gneiss) and the appearance of gneiss belonging to a higher horizon superior to the limestone (Hudson schist) on the south of the river. He says:

> "High cliffs of Fordham gneiss border the north shore of Spuyten Duyvil creek. The course of the creek is at any given point approximately parallel to the strike of the gneiss at that point, and the latter is everywhere seen to dip toward the creek. This definite relation between the windings of the creek and the variations in the strike of gneiss is due to the fact that the creek occupies the position of dolomite beds which formerly overlay the gneiss, but which have been almost entirely removed from view by solution and erosion. Several small outcrops of dolomite can still be seen at low water on the south shore of the creek dipping to the south along the cliffs of Hudson schist which line that shore" (loc. cit., p. 4, column 4).

My own observations do not confirm the above statement in all particulars, especially the uniform steep southerly pitch of the beds.

In the other localities where gneiss appears, forming both walls of the river, an exceedingly sharp longitudinal syncline must be postulated in order to bring in the limestone.

DETAILED STUDY OF SECTIONS

Order of presentation of results.—The data which have been secured bearing directly on the configuration of the surface of rock beneath the New York water fronts, refer both to the depth and to the character of the bed rock in the floors of those channels. They are considered in order, proceeding from the mouth of Spuyten Duyvil creek eastward about the island, so as to consider first Spuyten Duyvil creek, then the Harlem, East, and Hudson (North) rivers in succession. The sketch map of New York and vicinity shown in plate 35 will serve for location of sections. Inasmuch as the problem, so far as it is petrographical, is to locate the areas of limestone, it will be sufficient to refer to the harder rock as gneiss without attempting to refer it to one horizon or another.

Spuyten Duyvil bridge, Harlem river.—This bridge is not founded on the rock bed, but rests on piles. Wash borings were, however, put down to the bed rock by Mr C. B. Brush, the depths varying from 94 to 124 feet below mean high water. No record has been preserved regarding the kind of rock at the bottom, and it was probably not known. Through the courtesy of the engineers of the New York Central railroad, the writer was allowed to examine the samples taken from the bottom of these borings, but they afforded no clue regarding the character of the rock.*

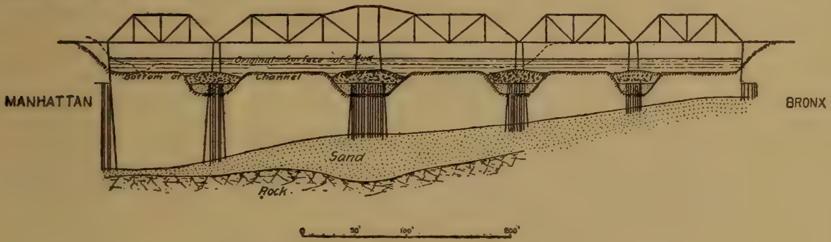

Figure 1.—*Sketch Map of Spuyten Duyvil Creek.*

Along the line of the swing-bridge.

Both north and south of the creek at that point the gneiss rises abruptly to form bluffs. In the railroad cut north of the creek local northerly pitches of the beds were found, and the conclusion is drawn that no southerly pitch sufficiently steep to carry the overlying bed of limestone to the bed of the river across the strike is probable.

The writer's view is that the stream here flows along a cross-fracture, as stated by Stevens† and apparently concurred in by Gratacap.‡ Under the causeway of the New York Central railroad across the northern edge of this gorge piles were driven to a depth of 35 feet without meeting rock.§

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*See, however, "The Spuyten Duyvil swing-bridge, etcetera." Engineering News, vol. xliii, 1900, pp. 397–398, figure 1.

†Loc. cit., p. 114.

‡L. P. Gratacap: Geology of the city of New York, 1901, p. 36.

§Information furnished by Mr F. L. Chase, engineer of bridges, New York Central and Hudson River Railroad Company.

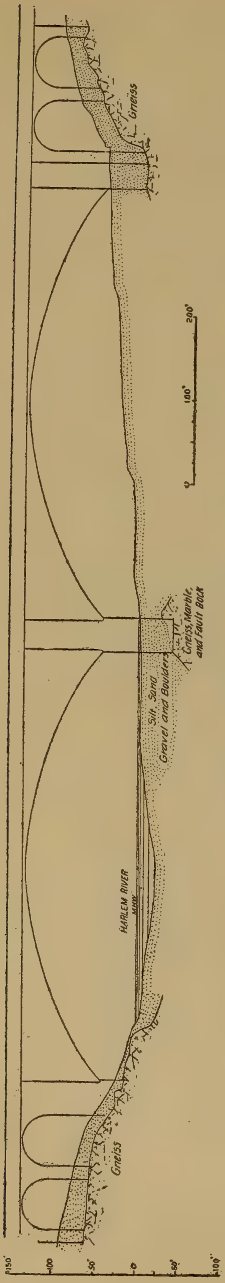

FIGURE 2.—*Section across Harlem River.*
On line of Washington bridge.

Kings bridge and Dyckmans cut.—In the vicinity of Kings bridge and along the line of the ship canal the limestone is much in evidence. The government work at Dyckmans cut consisted in the excavation of a canal through a reef of white marble, and is always referred to by the Corps of Engineers, United States Army, as the unique instance of excavating or dredging in limestone in all their operations about New York island.

Washington bridge, Harlem river.—This bridge has three piers—one on the west of the river, resting on gneiss, and two on the east side (see figure 2). The east pier rests on gneiss, while the middle pier is located in the alluvial material at the very edge of the water. This latter pier was sunk by caissons to "an irregular rock, partly gneiss, partly marble, with veins and pockets of very hard quartz."* Mr William R. Hutton, the chief engineer in charge of the construction, has obtained for the writer a very interesting letter from Mr George Leighton, his assistant engineer, regarding the rock found beneath the middle pier. A portion of Mr Leighton's letter follows:

> "The gneiss was nearly all of granular character, and the upper portions of the ledge had disintegrated. I do not recall that it was more micaceous than the ledge at and above Boscobel avenue, but it was much inferior to that in structure and density. The gneiss immediately overlying the marble was much harder—better material. My recollection is that the marble filled a fault in the gneiss, in width something over half the width of the caisson, and extending nearly parallel with the sides of the caisson. There were quartz deposits in the marble—one of considerable size, which would strengthen the fault theory. I carried a large specimen of the quartz to the office."

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* William R. Hutton: The Washington bridge over the Harlem river at One hundred and eighty-first street, New York city, a description of its construction, 1890, p. 21, plate xxxii.

It thus seems probable that the central pier of the Washington bridge is located on a line of faulting which follows the east bank of the river.

High bridge, Harlem river.—All but two of the seven piers of this bridge which are in the river are on piles; the other two, however, are on rock.* Dana has fortunately preserved † a sectional view of this bridge, "reduced from a tracing obtained for me by Mr Benjamin S. Church at the engineer's office in New York" (see figure 3). Mr Church was resident engineer in charge of the Croton water works. From this interesting section it appears that the walls of the Harlem gorge in this vicinity are formed of gneiss, which plunges down beneath the silt and other river deposits along a steep incline; and, further, that in the middle of the rock gorge there rises, pedestal like, a reef of marble which has furnished a base for the three central piers of the bridge.

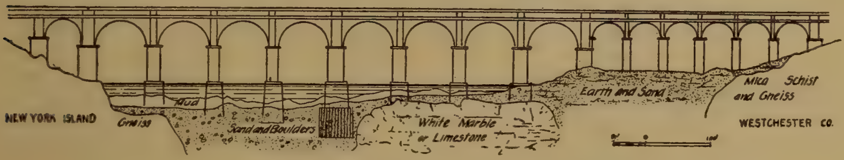

FIGURE 3.—*Section across Harlem River.*

On line of High bridge.

New New York aqueduct siphon under Harlem river.—The section of the aqueduct in this vicinity has furnished geological information of the first importance. The aqueduct crosses the river in an inverted siphon, the lowest arm of which is about 300 feet below the surface of the river. Vertical shafts descend through gneiss on either side of the river to this depth, and a horizontal connecting arm penetrates approximately 800 feet of "hard limestone or marble" beneath the river (see figure 4). The section shows the walls of this layer of limestone to be roughly parallel and to dip at very steep angles to the east. The first intention of the engineers was to locate the horizontal arm of the siphon at a more moderate depth (see figure 4), but on running the drift to the east a "crevice" was encountered with crushed stone at the boundary of the limestone. The report says:

> "Under Harlem river the gneiss and limestone were found to meet on a conspicuous diagonal line without any visible solution of continuity, the particles of the gray and of the white rock being so closely intermingled at the surface of contact that the exact line of separation could not be traced." ‡

The report and the section are therefore in accord in showing the

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* F. B. Tower: Illustrations of Croton aqueduct, New York, 1843, p. 110.

† Loc. cit., pp. 435–436.

‡ Report New York Aqueduct Commissioners, 1887 to 1895, p. 88 and sheet 32.

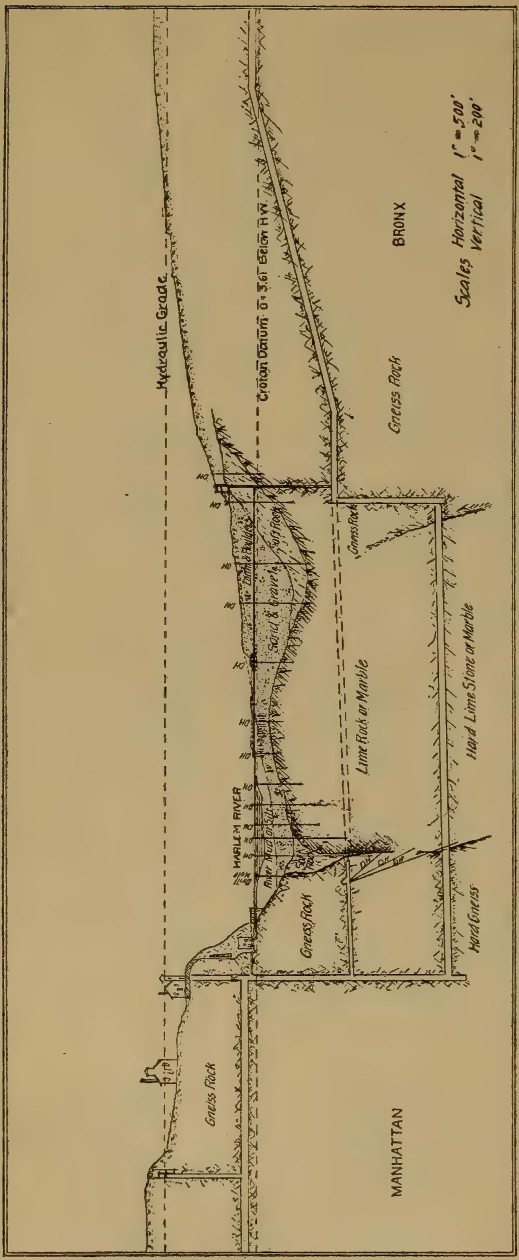
Hydraulic Grade
Croton Datum 0 = 3.61 Below H.W.
BRONX
Scales Horizontal 1" = 500'
Vertical 1" = 200'
Gneiss Rock
Boulders
Sand & Gravel
Soft Rock
Gneiss Rock
Lime Rock or Marble
Hard Lime Stone or Marble
HARLEM RIVER
River Mud or Silt
Gneiss Rock
Hard Gneiss
Gneiss Rock
MANHATTAN

Figure 4.—*Section across Harlem River.*
Along line of new New York aqueduct.

western boundary of the limestone beneath the river to be along a line of dislocation diagonal to the bedding. It is highly probable that the eastern boundary is also located on a parallel fault, but the evidence from this section is not conclusive.

Eighth Avenue bridge, Harlem river. — This bridge rests on piles. All efforts to learn the depth to which they were carried have been futile.

McCombs Dam (Central) bridge.—All piers of this bridge rest on a reef of gneiss which runs from one bank of Harlem river to the other at depths varying from 24 feet under the central pier to 30 feet at the west bulkhead line and 27 feet at the east bulkhead line. Mr Martin Gay, assistant engineer of the department of bridges, New York city, who has furnished me with this information, adds that "on the line of the bridge to the eastward the rock drops to an unknown depth in the swamp and comes to the surface again at One hundred and sixty-first street" (see figures

5 and 6). Mr Gay was in all the caissons himself, and thus was able to examine the rock personally. This reef crossing the Harlem is clearly the continuation of the Fordham Heights ridge, which was also once extended southward by a range of gneiss outcrops now largely removed.*

Soundings to rock east of Central bridge.—The data used in constructing this profile (see figure 6) were furnished by the department of public parks to Professor I. C. Russell, who, in his valuable paper on the Geology of Hudson county, New Jersey,† gives the depth of the underlying gneiss at all points in the section. This section not only covers the bottom of the river, but extends some 2,000 feet north of it into the lowland of Cromwells creek. It is interesting in showing how faintly the present channel is indicated in the configuration of the surface of the bed rock.

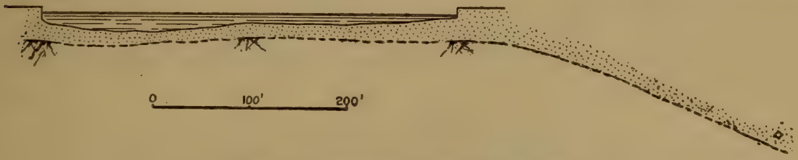

Figure 5.—*Section across the Harlem River.*

Along the line of McCombs Dam (Central) bridge.

New York Central Railroad bridge across Cromwells creek.—This bridge, as will be seen from the map, is almost a continuation to the eastward of the McCombs Dam bridge, and data which it furnishes should therefore be considered in relation to those of the last-mentioned section. The bridge rests on piles which go down 120 feet, but do not reach to bed rock.‡ It thus appears that the reef of gneiss which comes so near to the surface of the Harlem river at McCombs dam plunges off to great depths but a short distance farther to the east, the line of this declivity corresponding in direction with the extension of Cromwells creek northward or parallel

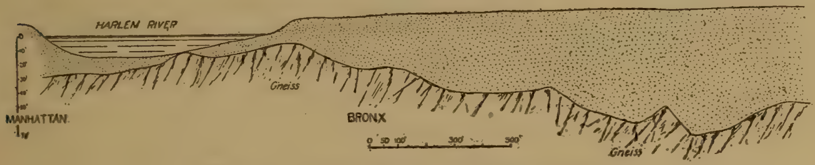

Figure 6.—*Profile of Rock beneath Harlem River.*

On line 400 feet east of Central bridge.

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*See Viele's map and a paper by Ries in Transactions of the New York Academy of Science, vol. x, 1891, pp. 113–114.

† Loc. cit., p. 75.

‡ Information furnished by Mr F. L. Chase, engineer in charge of bridges, New York Central and Hudson River Railroad Company.

with the faults believed to have occurred in the western gorge of the Harlem river. If they there exist, Fordham heights would appear to be a long "horst" or "brücke" lying between parallel faults and agreeing closely, both in size and orientation, with the "horst" of Washington heights, a little farther west.

One hundred and forty-fifth Street bridge.—This bridge has five piers, four of which rest on white marble and the fifth on "extreme hard-pan."* Crystalline limestone is also exposed at the surface near the New York end of the bridge. The section along this bridge reproduced in figure 7, like that at certain other bridges, affords no evidence that the river here flows in a rock gorge.

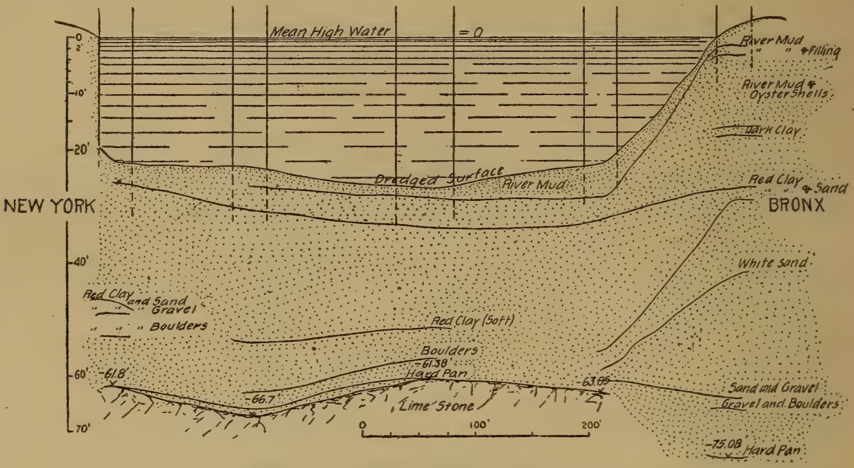
Mean High Water
= 0
0
2'
10'
20'
40'
60'
70'
NEW YORK
BRONX
River Mud
" " + Filling
River Mud + Oyster Shells
Dark Clay
Dredged Surface
River Mud
Red Clay + Sand
White Sand
Red Clay and Sand
" " Gravel
" " Boulders
Red Clay (Soft)
Boulders
-61.38'
Hard Pan
-61.8'
-66.7'
Lime Stone
-63.05
Sand and Gravel
Gravel and Boulders
-75.08
Hard Pan
0
100'
200'

FIGURE 7.—*Section across the Harlem River.*

Along line of One hundred and forty-fifth Street bridge.

Rapid Transit tunnel.—This tunnel connects Lenox avenue and One hundred and forty-first street, on Manhattan, with Westchester avenue, in the Bronx. The approximate surface of the rock in the vicinity of Harlem river along the line of this tunnel is brought out in the profile of figure 8. The rock penetrated is limestone.†

Madison Avenue bridge, Harlem river.—This bridge rests on piles, which at no point reach to bed rock.‡ Russell gives the data for a section across the river at this point.§

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* Information furnished by Mr F. W. Allen, engineer for the contractor, who also kindly supplied data for the section.

† Information and profile furnished by Mr George S. Rice, deputy chief engineer, Rapid Transit Railroad commissioners.

‡ Information furnished by Mr A. P. Boller, consulting engineer, and Mr McLean, engineer of the comptroller's office.

§ I. C. Russell: Geology of Hudson county, New Jersey. Ann. N. Y. Acad. Sci., vol. ii, 1882, p. 75.

Park Avenue Railroad bridge.—The approximate surface of the rock in this section is brought out in the sketch profile which has been furnished by Mr Alfred P. Boller, consulting engineer, who was the engineer in charge of construction (see figure 9). Gneiss is found near the present grade beneath the piers on both banks of the river. The north bank of the river is formed by a nearly vertical wall of gneiss, which was followed to a depth of 70 feet by the piles beneath one of the piers. The strike of this wall is, according to Mr Boller, about at right angles to the line of the bridge. This wall would appear to represent a line of dislocation. Beneath the central pier of the bridge a drill was put down 104 feet to either a ledge or a boulder of limestone. Mr Boller says:

> "We found some pieces of marble, which is probably the same as the Tuckahoe marble in Westchester county."

Third Avenue bridge, Harlem river.—In constructing this bridge the caisson of the southwest pier, which is 70 feet from the Manhattan shore, rests on a ledge of gneiss at a depth of 52 feet. The bottom of the caisson was 24 feet by 110 feet, and an unbroken area of gneiss extended the entire width of the caisson and was uncovered for 30 feet of its length.* The other piers of the bridge rested on boulders (see figure 10).

Second Avenue bridge.—The north and south abutments and the four piers of this bridge rest alike on the detrital material of the river. Borings were sunk beneath the piers to depths ranging from 40 to 48½ feet without encountering rock of any kind. The profile of figure 11 has been kindly furnished by Mr J. J. R. Croes, who was chief engineer in charge of construction.

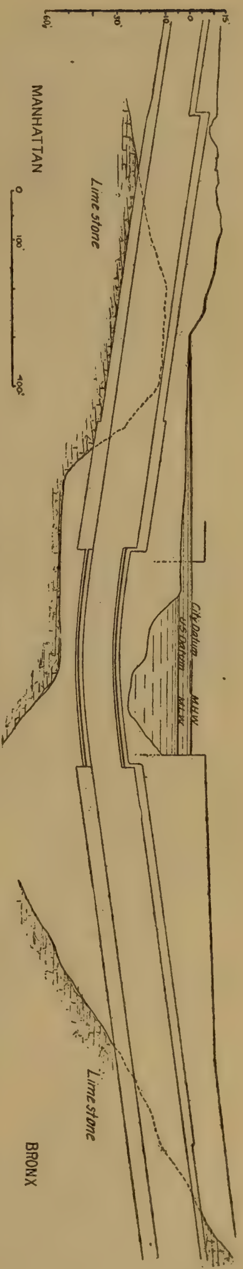

FIGURE 8.—*Section across Harlem River.*

From One hundred and forty-first street and Lenox avenue, Manhattan, to Westchester avenue, Bronx (Rapid Transit tunnel).

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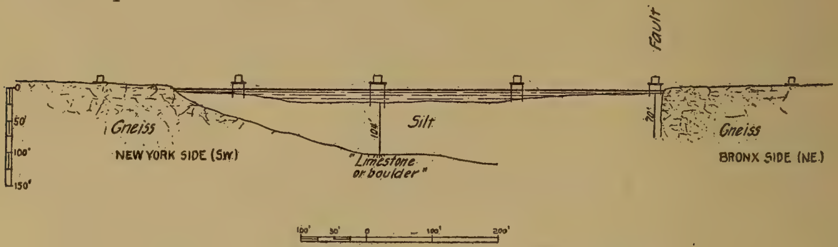
* Information furnished by Mr Edward A. Byrne, assistant city engineer, New York.

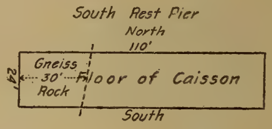
Willis Avenue bridge.—About 200 feet out from the Manhattan shore the center pier of this bridge, at a depth of 80 feet below mean high water, rests in part on a ledge of marble and partly on boulders. The other piers rest on boulders (see figure 12). Mr E. A. Byrne, assistant city engineer, has preserved a sample of the marble, which was submitted to the writer for examination. It is a white coarsely crystalline rock like that quarried at Tuckahoe.



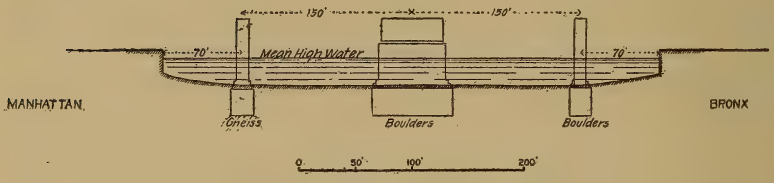
Fault
0
50'
100'
150'
Gneiss
NEW YORK SIDE (SW)
104'
Silt
"Limestone or boulder"
70'
Gneiss
BRONX SIDE (NE)
100'
50'
0
100'
200'

FIGURE 9.—*Section across Harlem River at Park (Fourth) Avenue.*

One hundred and twenty-fifth and one hundred and twenty-second Street reefs, East river.—The first mentioned of these is in the mid-channel of the East river off One hundred and twenty-fifth street, and the second about 300 feet off the foot of One hundred and twenty-second street. Both reefs are of gneiss and have been reduced in height by the Corps of Engineers, United States Army.*



South Rest Pier
North
110'
Gneiss
30'
Rock
Floor of Caisson
24'
South



150'
150'
70'
Mean High Water
70'
MANHATTAN
Gneiss
Boulders
Boulders
BRONX
0
50'
100'
200'

FIGURE 10.—*Section across Harlem River.*

Along line of Third Avenue bridge.

Projected Hell Gate railroad bridge.—The New York Connecting Railroad Company, of which Mr A. P. Boller, is chief engineer, has projected a double-track railroad bridge across the East river at Hell Gate from Long Island City to the Bronx.* Diamond drill borings have been made for piers at the crossing of Hell Gate.† Gneiss was found on the Long Island side at a depth of about 100 feet below mean high water. On the Wards Island side of this crossing the rock is hornblende gneiss.

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* Report of the Chief of Engineers, United States Army, 1896, part i, p. 106. The writer is indebted to Captain Edgar Jadwin, Corps of Engineers, United States Army, for information regarding the composition of these reefs.

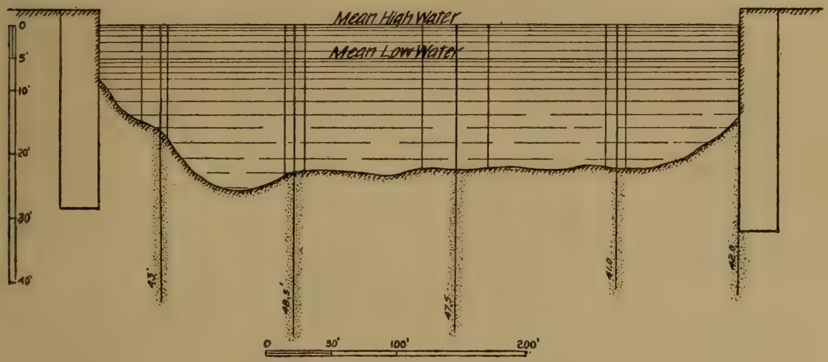
Mean High Water
Mean Low Water
0
5'
10'
20'
30'
40'
43'
48.5'
47.5
41.0
42.0
0
50'
100'
200'

FIGURE 11.—*Section across Harlem River.*

Along line of Second Avenue bridge.

Between Wards and Randalls islands the gneiss surface was found at a depth of only a few feet below tide.‡

Hell Gate reefs.—The government works at the entrance to this channel

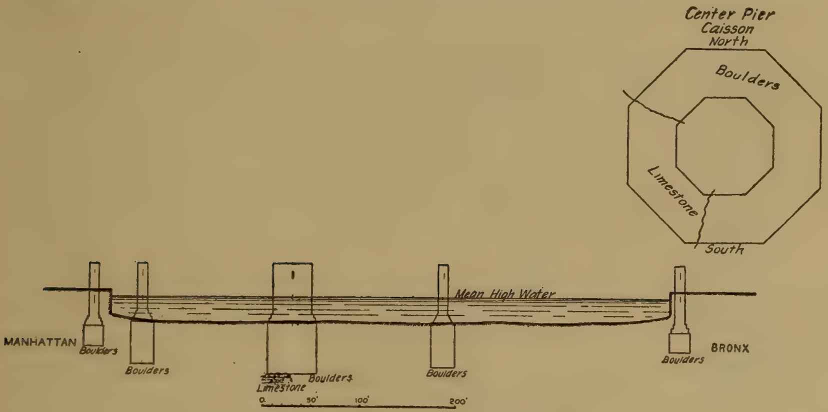
Center Pier
Caisson
North
Boulders
Limestone
South
Mean High Water
MANHATTAN
Boulders
Boulders
Boulders
Limestone
Boulders
Boulders
BRONX
0
50'
100'
200'

FIGURE 12.—*Section across Harlem River.*

Along line of Willis Avenue bridge.

included the removal of large masses of reef a considerable distance out from Hallets point, a shelving ledge extending into the ship channel from Mill rock, and the removal of the cap of Flood rock in the middle of the channel, the latter the greatest work of the kind ever attempted. All of these obstructions are of gneiss, and similar rock is to be found exposed on the south shore of Wards island on either side of the small bay which indents that shore. Together these exposures of gneiss make almost a complete section across the river.

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*See Engineering Record, vol. xli, 1900, p. 453.

†See plate xix for location of bridge.

‡Information furnished by Mr A. P. Boller, chief engineer.

East River Gas Company's tunnel (*Blackwells Island tunnel*).—There is considerable literature treating of the construction of this tunnel. A shaft was sunk on the New York side to a depth of 139 feet, from which point a drift was carried on a descending grade of 0.5 to 100 beneath both channels of the East river and Blackwells island to a vertical shaft on the Ravenswood, Long Island, side. The roof grades of the tunnel are on the New York side 104 feet below the level of mean low water and on the Ravenswood side 116.6 feet below the same datum plane. The writer is indebted to Mr J. Vipond Davies, one of the engineers in charge of the construction, for much information of scientific value obtained during the construction of this tunnel. Mr Davies states that in sinking drills they were in no place able to penetrate more than 5 or 6 feet into what appeared to be hard gravel, sand, and a great quantity of very large boulders lying on the bed of the river. It is probable that the strong tides of Hell Gate have scoured out all the finer material, leaving only such as was too large to be transported. It was thus found impossible by means of borings to determine in this vicinity the depth of bed rock below the river surface, but it was considered by the engineers in their work that the line of the bottom of the river was practically the surface of rock. The roof grade of the tunnel is approximately 32 feet below the deepest point of the river bed in the west channel and about 65 feet in the east channel. The accompanying profile (figure 13) has been slightly modified from one published by Aims in the Journal of the Association of Engineering Societies. The section is of special interest to geologists, particularly as regards the composition and also the struct-

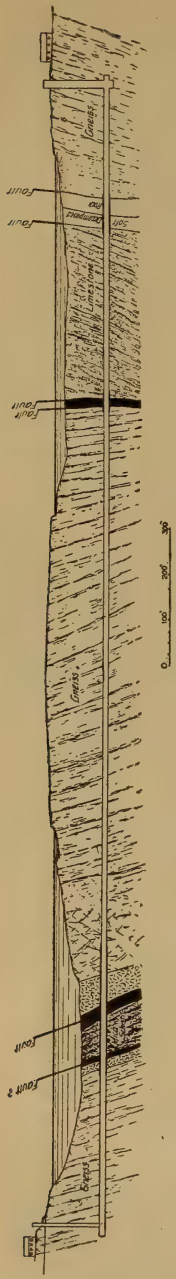

FIGURE 13.—*Section across East River.*
Along gas company's East River tunnel.

ural planes of the rock penetrated by the tunnel. Much attention has been given to the rock composition by the engineers who have written on this tunnel, and their descriptions have been supplemented by the petrographic studies of Professor Kemp. For the greater part of the distance the rock is a gneiss of varying hardness, in this respect reaching a maximum in the hornblende gneiss encountered under the east side of Blackwells island. Under the bottom of the west channel a considerable thickness of soft decomposed rock was found, which Kemp has shown to be, in part at least, the residue from the alteration of one large and a number of smaller pegmatite veins. Beneath the east channel a thickness of about 350 feet of hard white marble was found enclosed between soft decomposed bands, which appear to correspond to nearly vertical fissure planes. The loose material filling these zones about the fissures is in part decomposed pegmatite and in part altered mica schist. In a personal letter Mr Davies has added some valuable notes concerning the nature and direction of the fissures both in the east and the west channels. He says:

> "Under the New York end of the tunnel is highly micaceous gneiss rock. Just outside of the pier line it intersected a fissure. . . . Under the east channel is a seam of about 350 feet of dolomite, bounded on both sides by fissures of completely decomposed (and soapstone-like) mica schists. . . . The dip of these fissure faces is about 22 degrees off the vertical.* The strike is slightly west of north.
>
> "Curiously, when we were excavating the foundations for the Rainey bridge, which was to be built at Sixty-fourth street, New York, we found at the site of the pier on the west side of Blackwells island a fissure exactly corresponding in the direction and strike to the one tunneled through opposite Seventieth street. In this last case, however, although it appeared 15 feet wide at the top surface of rock (some 10 feet below mean low water), we excavated it entirely out to a sharp V, at a depth to the point of the V about 25 to 30 feet below mean low water."

Fissures found along the line of this tunnel seem, therefore, to be included in a parallel series, the strike of which is a few degrees west of north and the hade of which varies from 78 degrees east to a very steep angle west. One of the faults discovered under the pier of the Rainey bridge belongs to a different series following the course of the channels in this vicinity.

Projected but abandoned Rainey bridge.—The location of this bridge was to have been from the north side of Sixty-fourth street, in Manhattan, to the foot of what is named on the maps Harsell street, Long Island City, though as a matter of fact no such street exists. The work on this bridge is of scientific interest, chiefly because of the intersection of faults belonging in two different series, as described in the last paragraph.

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* This appears to refer to the fissures in the western channel only, for the sections of Aims and Jacobs show that those of the east channel are quite close to the vertical.—Ed.

East River bridge number 4 (*Blackwells Island bridge*).—This bridge is to connect Fifty-ninth street, Manhattan, with a point between Rogers and Charles streets, Queens. Diamond drills have been put down along the proposed line of this bridge beneath the piers on the Manhattan side of the river, on both shores of Blackwells island, and on the shore of Long Island City. The surface of the rock is in all cases but a few feet below the surface of the ground. The rock on the east side of Manhattan island at the water's edge slopes very abruptly toward the channel (nearly 45 degrees). On the west and east sides of Blackwells island the rock surface is at about the level of high water and is badly decomposed for a distance of from 2 to 5 feet below the surface. On the Long Island shore the rock surface is also at about the level of high water and is found more decomposed than upon the shores of Blackwells island, it having been necessary to remove about 15 feet of this material before suitable foundations could be secured. Through the courtesy of Mr R. S. Buck, former chief engineer in charge of this bridge, the writer was enabled to examine cores from all the drill borings and found them to represent a granitic type of gneiss.* From Mr H. A. La Chicotte, since engineer in charge, the section was obtained which has been reproduced in figure 14.

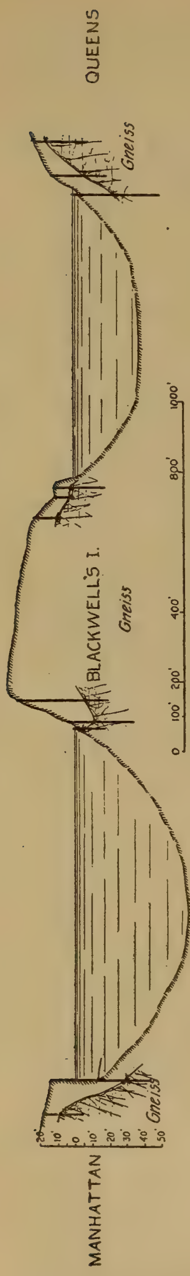

FIGURE 14.—*Section across East River.*
On line of East River bridge number 4 (Blackwells Island bridge).

It is quite likely that the decomposition of the gneiss at the shores along this section is to be explained in the same way as is the decomposed rock along the fissures in the Blackwells Island tunnel; namely, through the local fracturing of the rock and the consequent introduction of water from the river. During the construction of the Blackwells Island tunnel the operations were greatly hampered by the oozing into the tunnel of water and decomposed rock in the form of a thick mud. In the construction of the new New York aqueduct the same difficulty was encountered at the boundaries of the limestone (see figure 14).

---

* Information regarding East River bridge number 4 was obtained from Mr R. S. Buck, former chief engineer, and Mr H. A. La Chicotte, who succeeded him in charge of this bridge.

Abandoned East River tunnel.—The only work that was done on this tunnel was the excavation of a shaft in section 10 feet by 8 feet and 80 feet in depth to the grade of the proposed tunnel. The shaft was sunk 10 feet in the earth to the underlying gneiss, into which it was carried 70 feet. There occurred a very serious explosion when this stage of the work had been reached, much damage to property being caused and a number of persons seriously injured. The conditions are now favorable to an early resumption of the work and the ultimate completion of the tunnel.

Man-o'-war reef.—The Man-o'-war reef forms a continuation of Blackwells island to the southwestward and has the form of an elongated prow. Considerable work has been done by the engineers of the United States army in removing the upper portions of this reef. Through the courtesy of Captain Edgar Jadwin, of the Corps of Engineers, United States Army, the writer secured a number of specimens from this reef. These specimens represent respectively a granitic type of gneiss, a hornblende gneiss of undoubtedly igneous origin, and a dense basalt like that so characteristic of the Newark areas of the Atlantic border. It seems likely that this latter rock may be from a portion of a narrow dike within the series of crystallines.

Section on center line of Forty-second street produced.—Through the courtesy of Mr August Belmont and his chief engineer, Mr Allan A. Robbins, the data from the series of core drillings made in the bottom of the East river have been placed at my disposal. The revelations concerning the topography of the river bottom and of the nature and depth of the bed rock beneath are set forth in figure 15, which has been drawn from the blue prints furnished by Mr Robbins. The line of the section passes near the Man-o'-War reef, and those cores which were obtained near the banks of the river and near the Man-o'-War reef are all hard gneiss. Near the middle of the western channel drills (number 2 *A*) brought up a core of compact dolomite. All others, save those already described as from the vicinity of the reef and shores, were of decomposed rock material, which in some instances the drillers were unable to separate from the sand and silt immediately overlying. The samples from these drillings have, however, been placed at the writer's disposal and subjected to a careful microscopic examination. The material is throughout partially disintegrated gneiss, consisting of feldspar, quartz, and biotite, with smaller amounts of muscovite, magnetite, and garnet. Considerable differences in coarseness of texture are noted, and one specimen was even labeled clay. This specimen differed, however, in no respect from the others except in its greater fineness.

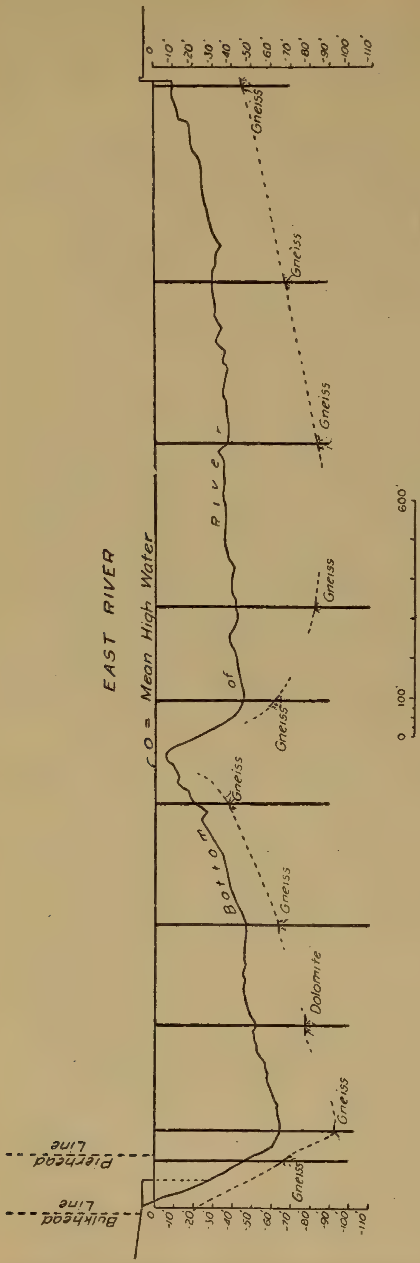
EAST RIVER
0 = Mean High Water
Bottom of River
Gneiss
Gneiss
Gneiss
Gneiss
Gneiss
Gneiss
Gneiss
Dolomite
Gneiss
Gneiss
Pierhead Line
Bulkhead Line
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
0
100'
600'

FIGURE 15.—*Section across East River.*
On center line of Forty-second street produced. (After Robbins.)

Tunnels of the Pennsylvania Railroad Company.—These proposed tunnels are to run from the area between Thirty-second and Thirty-third streets, Manhattan, to that between Flushing and Borden streets, Queens. Core drill borings on both shores of the East river along the line of these proposed tunnels have been made under the direction of Mr A. Noble, chief engineer of the company for the East River section. Between First avenue, New York city, and Front street, Long Island City, no less than 35 core borings and 112 wash borings have been made. The core borings, which are all on the landward side of the bulkhead lines, are in gneiss exclusively. The wash borings in the river give with much detail the surface of the rock bottom of the river over a belt about 600 feet wide on the Long Island shore, but they, of course, fail to reveal the nature of the rock at the bottom. The depths in the section of figure 16 are averaged from the values for approximately equal distances from the shores. Quite remarkable and sudden changes in level are, however, revealed by the individual borings. To bring out in some measure these differences in the profiles along the northern and southern margins of the belt it is only necessary to study the individual sections.

Twenty-sixth Street and Third Street reefs.—The first mentioned of these is located in the channel of East river off the foot of Twenty-sixth street, New York, at about one-third the distance to the Brooklyn shore. The Third Street reef is in mid-channel opposite the foot of Third street. From information received from Captain Jadwin, of the Corps of Engineers, United States Army, both reefs are of gneiss.

East River bridge number 2 (Williamsburg bridge).—This bridge, now approaching completion, connects Delancy street, Manhattan, with the space between the South Fifth Street and South Sixth Street piers, Queens. For the New York tower, anchorage, and approach, and for the Williamsburg tower, a large number of drill holes were sunk, those under the towers and anchorages with core drills. The rock, so far as encountered, is everywhere gneiss and the surface much more regular than in most other sections. Figure 17 is made from the extensive drawings kindly furnished by Mr H. A. La Chicotte, of the New York department of bridges. Through the courtesy of Mr R. S. Buck, the former chief engineer, the writer was permitted to examine the cores from the foundations of the towers and anchorages.

East River bridge number 3.—Diamond drill borings were put down at a number of points under each of the piers and anchorages of this bridge, and carried about 10 feet into the rock in every case. Through the courtesy of Mr R. S. Buck, chief engineer, the cores from all these borings were opened up for the writer's inspection. In all cases but one the

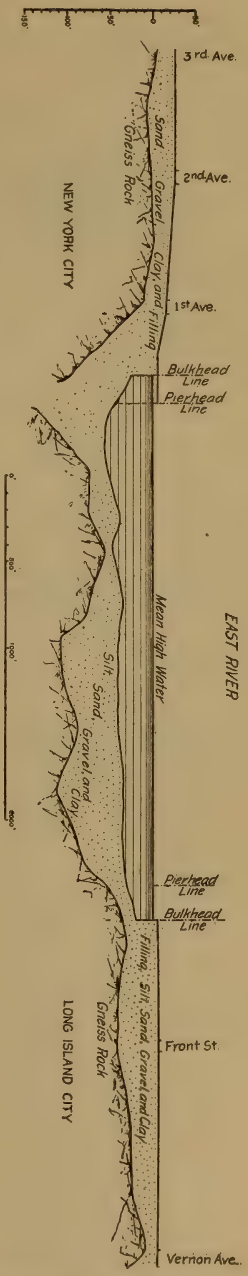
3rd Ave.
2nd Ave.
1st Ave.
Sand, Gravel, Clay, and Filling
Gneiss Rock
NEW YORK CITY
Bulkhead Line
Pierhead Line
Mean High Water
EAST RIVER
Silt, Sand, Gravel, and Clay
Pierhead Line
Bulkhead Line
Filling, Silt, Sand, Gravel and Clay
Gneiss Rock
LONG ISLAND CITY
Front St.
Vernon Ave.

FIGURE 16.—*Section across East River.*

On line of proposed tunnels of the Pennsylvania, New York and Long Island Railroad Company.

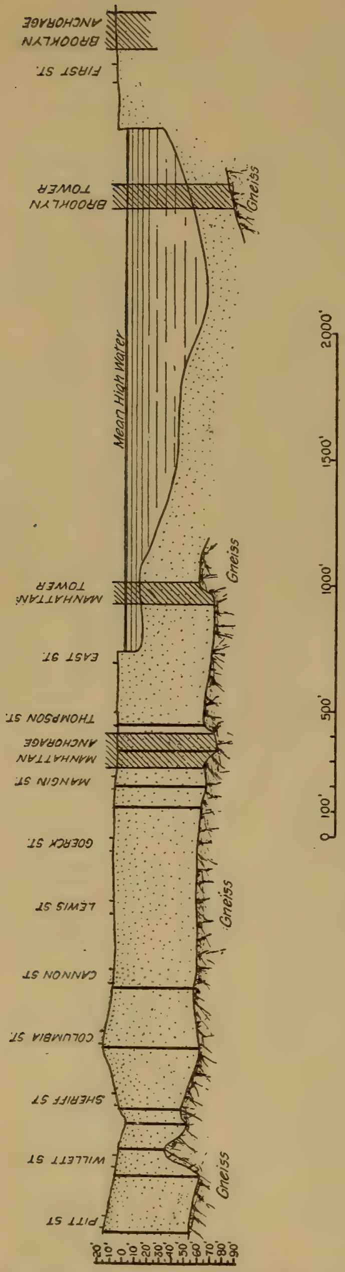
BROOKLYN ANCHORAGE
FIRST ST
BROOKLYN TOWER
Gneiss
Mean High Water
Gneiss
MANHATTAN TOWER
EAST ST
THOMPSON ST
MANHATTAN ANCHORAGE
MANGIN ST
GOERCK ST
LEWIS ST
Gneiss
CANNON ST
COLUMBIA ST
SHERIFF ST
WILLETT ST
Gneiss
PITT ST
0 100' 500' 1000' 1500' 2000'

FIGURE 17.—*Section across East River.*

Along line of East River bridge number 2 (Williamsburg bridge).

rock is of the granitic type of gneiss, which contains frequently small garnets. The exception is from hole number 2 near the center line, outer side of the New York tower, the rock from this core being a beautiful white dolomite. Figure 18 is a profile of the river along the line of this bridge, which shows the locations of both towers and anchorages.

Figure 19 shows the location of drill hole number 2 under the outer edge of the New York tower. The position of this drill hole between gneiss in holes on either side of it at the corners of the tower makes it likely that this occurrence of limestone is infaulted between walls of gneiss—mortised into gneiss—as was the case in Vosburg hill, Toms hill, and elsewhere in the Sheffield valley, or has been pinched sharply in a fold. The depth of the rock surface below mean high water is, under the New York anchorage, from 72 to 84 feet, under the New York tower from 108 to 133 feet, under the Brooklyn tower 90 to 97 feet, and under the Brooklyn anchorage 68 to 74 feet.

Brooklyn bridge.—The New York and Brooklyn piers were carried down to the bed rock. In the report of the chief engineer the following statements are made in reference to the foundations beneath the New York tower:

"The projecting peaks of bed rock which already made their appearance at 75 feet were blasted down for some distance under the shoe. . . . The rock is the ordinary gneiss found on Manhattan island with a dip almost vertical."*

Russell states, on the authority of information furnished by the department of docks, that the borings for foundations of the New York tower, made September 10 to 23, 1877, were carried to a depth of 107.6 feet, and penetrated mica schist to a depth of 6.4 feet. He quotes Mr F. Collingwood, chief engineer, as follows:

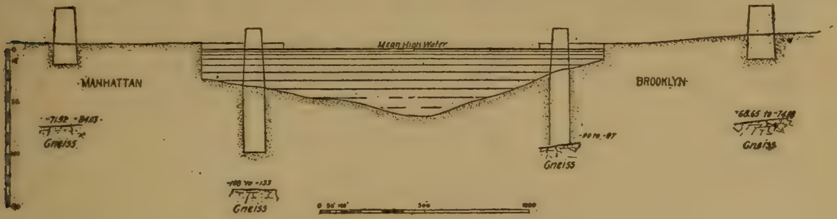
Mean High Water
MANHATTAN
BROOKLYN
-71.92 -84.03
Gneiss
-108 to -133
Gneiss
-90 to -87
Gneiss
-68.65 to -74.10
Gneiss
0 50 100
500
1000

FIGURE 18.—*Section across East River.*

Along line of East River bridge number 3.

> "The rock on which the pier foundations rest is gneiss, with a very irregular surface; in a place 172 by 100 feet the depth below high tide varied from 75 to 94 feet. The caisson was stopped at 78 feet."

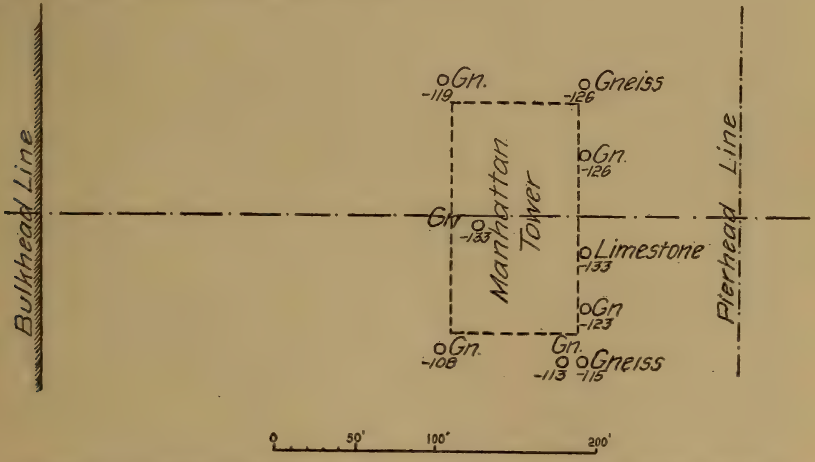
Bulkhead Line
Pierhead Line
Manhattan Tower
Gn.
-119
Gneiss
-126
Gn.
-126
Gn
-133
Limestone
-133
Gn
-123
Gn.
-108
Gn.
-113
Gneiss
-115
0
50'
100'
200'

FIGURE 19.—*Location of Drill Holes under New York Tower of East River Bridge Number 3.*

At the Brooklyn tower mica schist was found at a depth of 88 feet.†

Coenties reef.—This reef of gneiss is located in the East River channel about one-third of the distance from the Battery to Joralemon street, in

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* Reports of Executive Committee, Chief Engineer, and General Superintendent of the New York Bridge Company, Brooklyn, 1872, p. 26.

† Russell, quoting F. Collingwood, loc. cit.

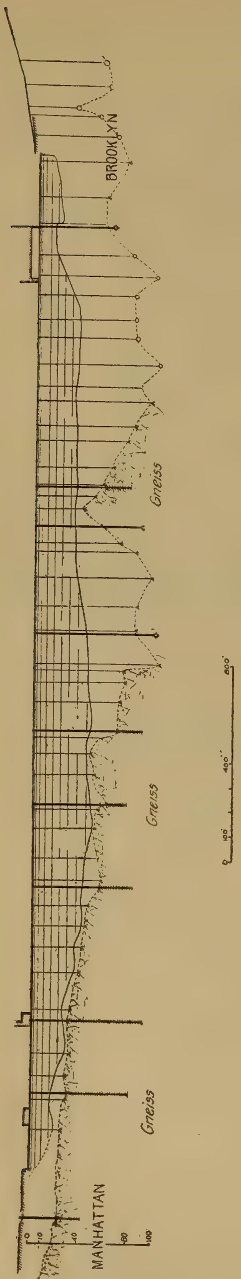

FIGURE 20.—*Section across East River.*

Along line of New York-Brooklyn tunnel (Rapid Transit tunnel).

Brooklyn. It is therefore quite near the line of the Whitehall Street tunnel, now being constructed.

Rapid Transit tunnel under East river.—The course of this tunnel is from the foot of Whitehall street, Manhattan, to the foot of Joralemon street, Brooklyn. The data from the preliminary wash and core drill borings for this tunnel are set forth in figure 20, which is reproduced from supplementary drawing 2–D–24 of the Rapid Transit Railroad commissioners. On authority of Mr George S. Rice, deputy chief engineer for the commissioners, the rock of all the cores is gneiss, no limestone being anywhere found in the section. The section is nearly complete across the river, there being, however, two deep channels separated by a sharp reef about a quarter of a mile from the Brooklyn shore, the bottom of which was not found by the drills at the depth of about 100 feet. The quite remarkable and abrupt changes of level shown by the surface of bed rock is in all respects of the type revealed by the borings of the same commission along the line of Broadway between the Battery and Union square.

Deep well on north shore of Governors island.—This well entered the rock at a depth of 69 feet 10 inches. It had, when last reported to the writer, been carried to a depth a little in excess of 1,800 feet, and had penetrated a micaceous type of gneiss for the entire distance.* The same type of rock is said to occur on the south shore of the island.

Diamond reef.—This obstruction to navigation, which is now being removed, is located in mid-channel a little north of Governors island in the direction of Coenties reef. Like the latter, it consists of the common type of gneiss.

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*Information furnished by John Sampson, chief quartermaster, Governors island, New York.

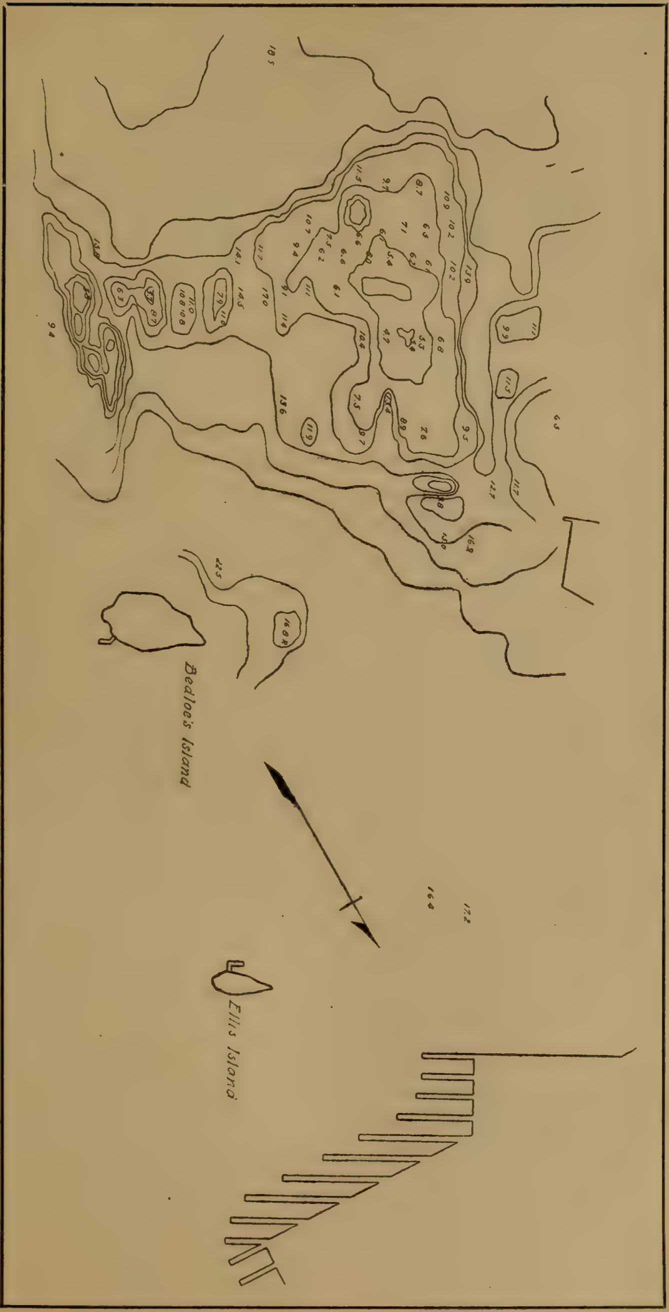
Bedloe's Island
Ellis Island

FIGURE 21.—*Rock Surface beneath the "Jersey Flats."*

From borings made by the Corps of Engineers, United States Army.

Reef off Battery.—A small reef has been found recently in the North river about a quarter of a mile west-southwest from pier A, with least depth of 28 feet at mean low water. The rock is gneiss, as are all the other reefs in the channels about New York island.

Jersey flats.—The area of the Jersey flats to the west and southwest of Ellis and Bedloes islands has been investigated through the medium of borings made under the direction of the Corps of Engineers, United States Army,* to determine the practicability of constructing a new channel in that vicinity. The rock contours and the depths to rock measured from mean low water are given on figure 21. The rock encountered by the drills was in all cases gneiss "nearly vertically stratified."

For the data entered on the map of the New Jersey flats I am indebted to Lieutenant Colonel C. W. Raymond, of the Corps of Engineers, United States Army. Data are not available concerning the depth of bed rock beneath Ellis island. For the foundation work of the new Ellis Island hospital penetration tests were made, using a $\frac{3}{4}$-inch iron rod. On the south side of Ellis island piles were driven into hard bottom at depths ranging from 16 to 23 feet at mean low water. No rock was, however, encountered. Buttermilk channel has been dredged to a clear depth of 26 feet below mean low water without uncovering rock in place.

Hudson River tunnel from Jersey City to New York (McAdoo tunnel).—The section of this tunnel (figure 22) published by Spielmann and Brush † shows that a reef of rock with a steep western and a gradual eastern slope rises near the east bank of the river along the line of the tunnel. The highest point of this reef, along the line of the tunnel, was at a depth of 89 feet below mean high water. The tunnel was first abandoned because of the difficulty of passing from the air locks to the rock, but the enterprise was again taken up, and has since been successfully carried through to completion as the McAdoo tunnel, of which Mr Charles M. Jacobs has been the chief engineer (see figure 22).

Projected Hudson River tunnels of the Pennsylvania Railroad Company.—These tunnels, six in number, are to run from Shippen street, Weehawken, to West Thirty-fourth street, New York. Core-drill borings have been made upon the Weehawken shore, extending out to a point 700 feet from the Weehawken shore, from which wash borings were taken at intervals of 500 feet or less to the Manhattan bulkhead line, from which latter point wash and core drills were put down across the

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* Survey of a point between Ellis island and the docks of the New Jersey Central railroad to a point between Reef light and Constable hook in waters of New York bay, New Jersey. Report of Major G. L. Gillespie, Corps of Engineers, United States Army, Appendix E 18. Annual report of Chief of Engineers for 1882, pp. 719–724.

† Arthur Spielmann and Charles B. Brush: The Hudson River tunnel. Trans. Am. Soc. Civ. Eng., vol. ix, 1880, pp. 259–277, plate viii.

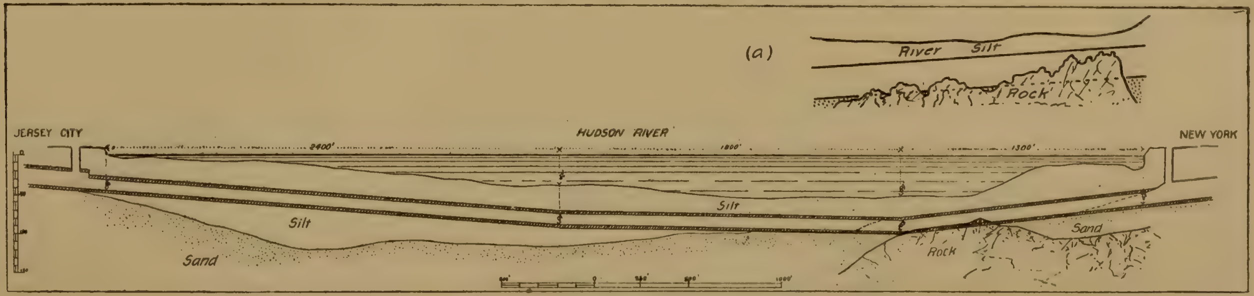
(a)
River Silt
Rock
JERSEY CITY
HUDSON RIVER
NEW YORK
2400'
1800'
1300'
Silt
Silt
Sand
Sand
Rock

FIGURE 22.—*Section across Hudson River.*

On line of Jersey City-New York tunnel.

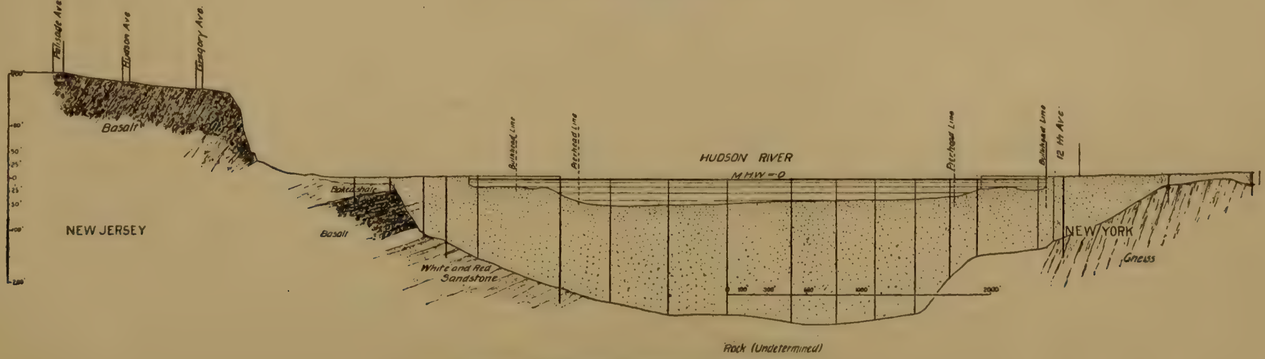
Palisade Ave
Hudson Ave
Gregory Ave.
Basalt
Baked shale
Basalt
White and Red Sandstone
NEW JERSEY
Bulkhead Line
Pierhead Line
HUDSON RIVER
M.H.W.=0
Pierhead Line
Bulkhead Line
12 th Ave
NEW YORK
Gneiss
Rock (Undetermined)

FIGURE 23.—*Section across Hudson River.*

On line of proposed tunnels of the Pennsylvania Railroad Company.

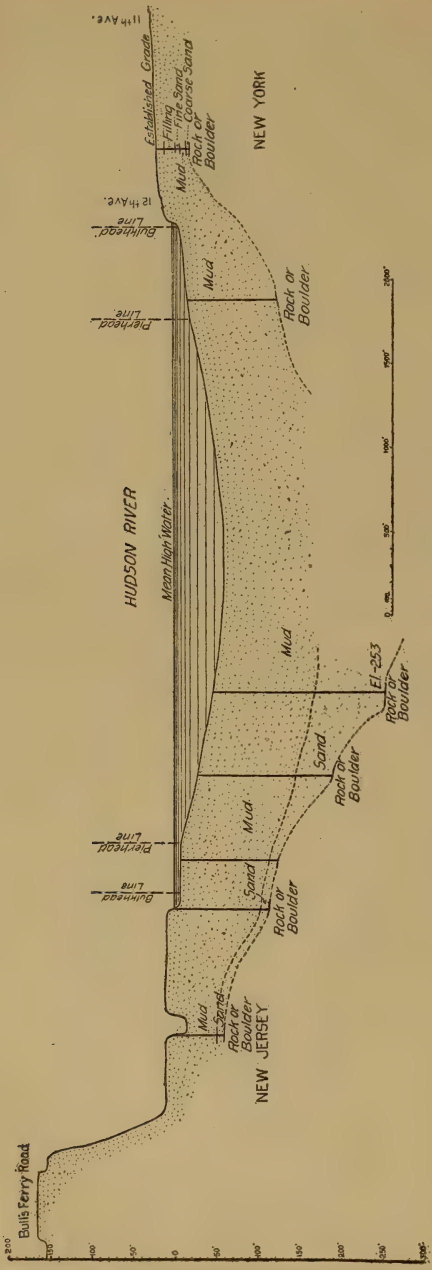
11th Ave.
Established Grade
Filling
Fine Sand
Coarse Sand
Rock or Boulder
Mud
NEW YORK
12th Ave.
Bulkhead Line
Pierhead Line
Mud
Rock or Boulder
HUDSON RIVER
Mean High Water
Mud
El-253
Rock or Boulder
Sand
Rock or Boulder
Mud
Pierhead Line
Bulkhead Line
Sand
Rock or Boulder
Mud
Sand
Rock or Boulder
NEW JERSEY
Bulls Ferry Road
0'
500'
1000'
1500'
2000'

FIGURE 24.—*Section across Hudson River Opposite Fifty-ninth Street.*

island to connect with the East River section (see page 170). The results obtained from the borings in the Hudson River section are displayed in figure 23, which is reduced from a drawing furnished the writer by Mr Charles M. Jacobs, chief engineer of the North River section. On the Weehawken shore the core drills were driven to different depths, the maximum depth of 237.8 feet being reached in the hole sunk 700 feet out from the shore. In all of these borings only Newark formations were encountered, and in all save one only red and white varieties of sandstone. In drill hole number 13, which is nearest the foot of the Palisades, the section penetrated by the drill showed baked shale between the depths of 20 and 68 feet, and below that point, to a depth of about 80 feet, Newark basalt. The sandstone slopes away from the shore towards the bluffs along a low angle. On the Manhattan shore the nature of the slopes toward the channel indicate that the gneiss continues to the bottom, though the borings are all wash borings.

Proposed New York and New Jersey bridge.—This project contemplated at first a cantilever bridge and later a stiffened suspension bridge across Hudson river at such place between Fifty-ninth and Sixty-ninth streets as should be approved by the Secretary of War.

A line of soundings to rock was made across the river, starting from a point between Fifty-ninth and Sixtieth streets, with results which are set forth in figure 24.* Mr Charles Macdonald, who made the borings for this section, informed the writer that the apparatus used was not sufficiently accurate to determine the profile all the way across the river. The figure, which discloses the results of wash borings, records "rock or boulder" at the bottom, inasmuch as the drill did not enter the obstruction. Mr Macdonald has furnished the additional information to that afforded by the section, that at a point 2,000 feet east of the bulkhead line on the New Jersey shore, or near the middle of the river, rock was found at a depth of 300 feet below mean tide. Before reaching the rock the boring tool passed through 240 feet of silt and sand. By reason of the very meager information concerning the bottom of the Hudson river, this section is of very considerable interest.

Conclusions respecting the Origin of the Channels

HARLEM RIVER

From the above it appears that little correspondence between the directions of belts of limestone or dolomite and of the New York water front can be established, except within the stretch between Kings bridge and McCombs Dam bridge, where the observed facts point to the occurrence of a narrow strip of limestone dropped down between nearly vertical faults. In other portions of its course the Harlem river flows over limestone or gneiss, but in all instances in a direction transverse to the strike and to the probable longer axes of the rock areas. The two reefs of gneiss over which the stream flows are located at McCombs dam and between Third and Fourth avenues. At the first-mentioned locality the backbone of the reef lies at a very moderate depth below the surface, from which in both directions the slope plunges away to a very considerable depth; as shown by the fact that the piles beneath the bridge of the New York Central and Hudson River Railroad Company over Cromwells creek were driven to a depth of 120 feet without meeting rock.

The Harlem River sections, which are furnished by the numerous bridges across it, show clearly that it is not a simple erosion valley resulting from the cutting of the stream. In the north-south and north-northwest south-southeast stretches of the river the rock banks are generally not in evidence, and even when they are they do not always correspond in position with the present banks. The bed of the stream appears to be not a uniform decline in a single direction, or made up of slopes in two directions from an intermediate point, but the floor is marked by sudden changes of level, particularly, however, where the reefs of gneiss cross it at McCombs dam and at Third avenue, thus connecting ridges of gneiss on the north with their extensions on the south.

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* Specifications for a suspension bridge over the Hudson river at New York. Engineering News, vol. xxxiii, March 7, 1895, pp. 159-160. (Figure.)

EAST RIVER

Under East river limestone has been found at but three localities—under the eastern channel at Blackwells island, in the western channel on the Forty-second Street section, and in one of the drill holes beneath the Manhattan pier of East River bridge number 3.* The limestone east of Blackwells island is probably enclosed between parallel fault walls, and would appear to have been dropped down along them. These fault walls are, however, not parallel to the gorge of the river, and the limestone belt is, with much probability, soon cut off by faults which follow the direction of the gorge.† The multiplied observations of gneiss, and gneiss only, beneath bridge piers and in tunnels in many sections of East river, the numerous reefs of the same rock in midchannel, and, more than all, the nearly complete section of gneiss across the river at the Battery, at Forty-second street, and the nearly complete section at Hell Gate—these multiplied observations leave little room for doubt that the rock bed of this river is mainly of the harder rock (see plate 35).

HUDSON RIVER

Regarding the bed rock beneath North river, comparatively little is known. The great depth of this river in this vicinity and its thick floor of drift and silt make it unlikely that very much will be learned about its rock bed in the near future. There is no reason to suppose that limestone may not underlie certain portions of it, though there is little reason to assume that it does. The rock of the eastern shore is largely gneiss and that of the western shore to the southward of the Palisade border (south of the principal bend at Weehawken) is also either gneiss or serpentine (see plate 35). The origin of the North River channel is sufficiently accounted for, however, by its position along the contact of the Newark beds with the crystallines. That this border is a fault border seems to be abundantly proven, not only by its markedly rectilinear extension, by the great scarp of basalt, and by the inferior position of the newer terrane as revealed by surface development,‡ but especially by the new borings along the line of the proposed tunnels of the Pennsylvania Railroad Company (see figure 22 and page 176).

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* Limestone is mentioned either in ledges or blocks at Corlears hook by some of the earlier writers, but from recent borings it seems certain that boulders are referred to.

† See ante, p. 167.

‡ Cf. Bull. Geol. Soc. Am., vol. 13, 1902, p. 143.

As to the origin of the channels of Spuyten Duyvil creek and of the Harlem and East rivers, in the opinion of the writer their directions have been largely determined by lines of jointing and displacement. Regarding the Spuyten Duyvil stretch, however, the facts are meager, and the problem is not free from doubtful indications.

Former Hydrography of Manhattan Island

Owing to the early importance of Manhattan island and to the fact that the gridiron of streets and avenues was laid out by surveys before any considerable change in topography had been wrought by man, we are in possession of unusually high-grade maps for the period in which they were made. Randall's map of the island was published in sections between the years 1811 and 1891. This map, which is now preserved in the office of the commissioner of public works, comprises four volumes of 92 sheets each. The individual maps are 25 by 37 inches, and are on a scale of 100 feet to the inch. Randall gives the precise location of all the old farms in their relation to water-courses and topography. General Viele's map, published in 1874,* is on a scale of 1,000 feet to the inch, and is based on Randall's map. It shows the original shoreline of the island, the made land, the drainage system, the topography, and the location of each rock exposure south of Manhattanville, all superimposed on the gridiron of streets and avenues. The accuracy of this map has been abundantly attested by engineers, real-estate men, and others who habitually use it, and, so far as exposures of rocks are concerned, it has been attested by the writer, both by comparison with the early reports of geologists on Manhattan island and by examination in the field. The made land and the hydrography have been reproduced in plate 35. It will be noted in how large a degree there is accord between the drainage directions and the directions of streets and avenues.

As an indication that this orientation of the drainage has been to a large extent determined by planes of fracture, it is interesting to consult the recent map by Julien, showing the location and orientation of the principal dikes on the island. These dikes quite generally run along the avenues (see plate 35). Julien has shown also that cross-fracturing is a common feature of the rocks of the Manhattan uplands, and has given instances of definite cross-faults directed nearly at right angles to the avenues or along the cross-streets. Thus the fissure planes which become occupied by the dikes and the perpendicular series described by Julien (often occupied by quartz lenses and pegmatite) correspond very closely in direction with the two series making up the main drainage system. The writer's observations show that many of the most prominent joint planes in the rocks of the island have the direction of the cross-fissures—north 60 degrees west.*

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* Topographical atlas of the city of New York, by Egbert L. Viele.

The role of the dolomite in fixing the locations of the present channels would thus appear to have been a subordinate one except in so far as the direction of its boundaries has been determined by fissure planes.

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* Cf. Bull. Geol. Soc. Am., vol. 15, 1904, p. 556.

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SOME CRYSTALLINE ROCKS OF THE SAN GABRIEL MOUNTAINS, CALIFORNIA *

BY RALPH ARNOLD AND A. M. STRONG

(*Presented before the Society December 30, 1904*)

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INTRODUCTION

The following paper embodies the results of some studies which were begun by the writers in 1897, while students in the department of geology at Leland Stanford Junior University, and which have been continued intermittently ever since. The analyses were made by the junior author in the laboratories of the university. The writers are indebted to Dr James Perrin Smith, of Stanford University, and to Dr Waldemar Lindgren, of the United States Geological Survey, for helpful suggestions relating to the preparation of the paper.

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* Published by permission of the Director of the U. S. Geological Survey.

LOCATION OF THE SAN GABRIEL MOUNTAINS

The San Gabriel mountains are a group of more or less intimately associated ridges and peaks occupying the territory between Cajon pass, in San Bernardino county, and the Santa Clara river, in Los Angeles county, their greater portion lying in the latter. They comprise an area of about 50 by 25 miles, nearly all of which lies within the confines of the San Gabriel timber reserve. The chain is exceptional in that its axis lies oblique to (and in some instances nearly perpendicular to) those of most of the other prominent ranges of California. What genetic relation exists between this group and the Sierra Nevada, Mount Diablo, and other ranges north of it is yet to be determined, but much light will

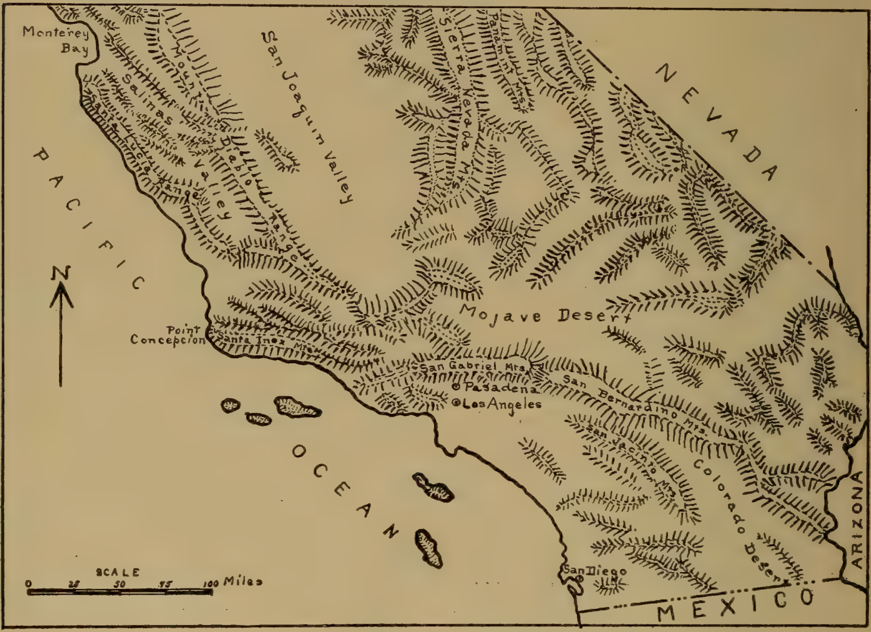
Monterey Bay
Mount Diablo Range
Salinas Valley
Santa Lucia Range
San Joaquin Valley
Sierra Nevada Mts.
Panamint Mts.
NEVADA
PACIFIC
N
OCEAN
Point Concepcion
Santa Inez Mts.
Mojave Desert
San Gabriel Mts.
Pasadena
Los Angeles
San Bernardino Mts.
Colorado Desert
San Diego
ARIZONA
MEXICO
SCALE
0 25 50 75 100 Miles

FIGURE 1.—*Sketch Map of Southern California.*

Showing relation of the San Gabriel to the other mountain chains.

doubtless be thrown on the subject by a study of the region at the southern end of the San Joaquin valley, where the axes of several of the ranges appear to focus.

TOPOGRAPHY

The San Gabriel mountains are divided into two more or less distinct ranges by streams which flow in easterly or westerly directions approximately parallel to the length of the chain. The most prominent of these streams is the San Gabriel river, which cuts nearly through the center of the group from south to north, and whose east and west branches separate the major portion of the southern or Sierra Madre range from the rest of the mountain area. The Middle Fork of Lytle creek, immediately west of Cajon pass, and Tujunga canyon, north of La Canada, nearly complete the separation of this southern border range from the northern mass. The Sierra Madre range is long and narrow, averaging only about 6 miles in width. Its sides are precipitous and are cut by short, deep, narrow canyons. The steep southern face of the range probably represents an ancient and bold fault scarp, which, however, has been considerably altered by erosion since its origin. The average height of the Sierra Madre is something over 6,000 feet, its highest point, Cucamonga peak, however, reaching an elevation of 8,911 feet. Great detrital fans, varying in area and depth with the size of their parent streams, stretch out from the southern base of the Sierra Madre over the San Gabriel valley, which borders the mountains on the south. North of the Sierra Madre is an elongated and complex range of ridges and peaks which culminates near the eastern end of the group in San Antonio peak ("Old Baldy"), elevation 10,080 feet. The slopes in this northern area are more gentle and the relief less sharp than in the southern, the outlying hills of the former grading off into the buried valleys of the Mojave desert, which bounds the San Gabriel mountains on the north.

The Verdugo mountains and the San Rafael hills are isolated portions of the San Gabriel mountains lying south of and separated from the latter by La Canada, a valley averaging nearly 2 miles in width, which runs for several miles parallel to the western end of the Sierra Madre range. At the eastern end of the San Rafael hills and La Canada lies Pasadena, while 9 miles southwest of the latter is Los Angeles, the chief city of southern California.

The rocks described in this paper were collected for the most part during reconnaissance trips over the following territory: Mount Lowe railroad to summit of mount Lowe, Rubio canyon, Eaton canyon, Big Santa Anita canyon, Mount Wilson toll-road, Sierra Madre-Mount Wilson

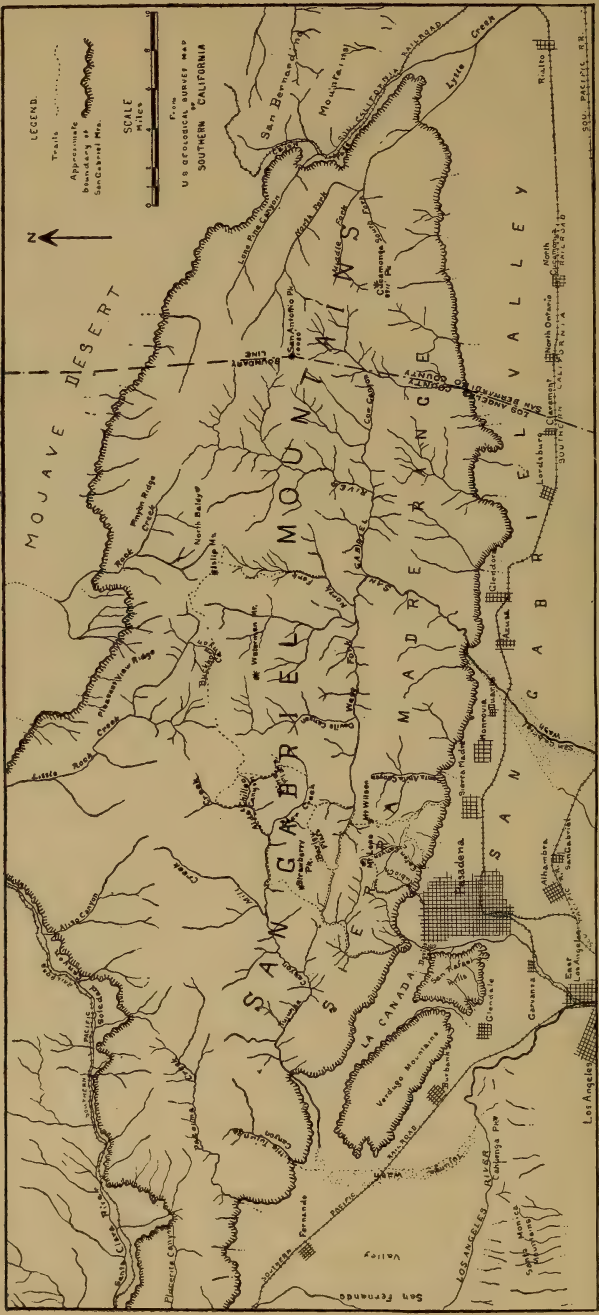
LEGEND.
Trails
Approximate boundary of San Gabriel Mts.
SCALE
Miles
0
2
4
6
8
10
From U S GEOLOGICAL SURVEY MAP OF SOUTHERN CALIFORNIA
N
MOJAVE DESERT
SAN GABRIEL MOUNTAINS
SIERRA MADRE RANGE
SAN GABRIEL VALLEY
SAN FERNANDO VALLEY
LA CANADA
San Bernardino Mountains
Verdugo Mountains
Santa Monica Mountains
LOS ANGELES COUNTY
SAN BERNARDINO COUNTY
BOUNDARY LINE
San Antonio Pk.
Cucamonga Pk.
North Baldy
Lone Pine Canyon
North Fork
Middle Fork
South Fork
Coe Canyon
San Gabriel River
West Fork
North Fork
Waterman Mt.
Islip Mt.
Pinyon Ridge
Rock Creek
Pleasant View Ridge
Little Rock Creek
Buckhorn Cr.
Devils Canyon
Santa Anita Canyon
Mt. Wilson
Mt. Lowe
Strawberry Pk.
Mill Creek
Alise Canyon
Soledad
Pacoima
Tujunga Canyon
Placerita Canyon
Santa Clara River
Southern Pacific
Lytle Creek
Santa Fe Railroad
Southern California Railroad
Sou. Pacific R.R.
Rialto
North Cucamonga
North Ontario
Claremont
Lordsburg
Glendora
Azusa
Duarte
Monrovia
Sierra Madre
Pasadena
Alhambra
San Gabriel
East Los Angeles
Los Angeles
Garvanza
Glendale
San Rafael Hills
Burbank
Fernando
Cahuenga Pk.
Los Angeles River
Wash

FIGURE 2.—*Sketch Map of the San Gabriel Mountains.*

trail, Sturtevants Camp trail, Mount Wilson-West Fork-Pine Flats trail, Chillao canyon, mount Waterman, Alder creek, upper Tujunga canyon, and, in the region west of Pasadena, Devils gate and the southern portion of the San Rafael hills.

As no topographic maps of the region were available at the time of the inauguration of the work, no effort was made to map the different rock areas, and as a consequence not as much information concerning the relations existing between the different types was obtained as would have been the case had the work included detailed field differentiation and areal mapping.

PREVIOUS LITERATURE

For an interesting mountainous region of over 1,200 square miles in extent, located in as important a section of country as that in the vicinity of Los Angeles, the San Gabriel chain has certainly received very little notice from geologists.

Doctor Trask, first state geologist of California, in 1855, referring to the geology of the San Bernardino mountains (in which he includes the San Gabriel and all other ranges from the San Jacinto to the Santa Inez), says: *

> "These mountains are made up for the most part of the primitive rocks, and consist chiefly of the granitic series. They form by far the most of all the higher ridges and more elevated peaks belonging to the chain."

In 1857 Blake † in his Pacific Railroad Survey report mentions compact and gneissose granite, talcose slates traversed by quartz veins, and trappean rock as occurring in the Cajon pass.

Slate, hornblende rock, and gneiss were found by Whitney, ‡ state geologist from 1860 to 1874, as float in the mouth of the San Gabriel canyon.

In 1900 Claypole § presented a paper on the "Sierra Madre near Pasadena" before the Cordilleran Section of the Geological Society of America, in which he described that range in a very general way, dwelling mostly on its relation to the region south of it.

Hershey || in 1902 mapped the western end of the San Gabriel mountains as "plutonic" and the eastern end as "granite." He also men-

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* J. B. Trask: Report on the geology of the Coast ranges. Cal. Sen. Doc., no. 14, 1855, p. 20.

† Wm. P. Blake: Pac. R. R. Report, vol. v, 1857, p. 88.

‡ J. D. Whitney: Geol. Survey of California. Geol., vol. i, 1865, p. 172.

§ E. W. Claypole: Bull. Geol. Soc. Am., vol. 12, 1901, p. 494.

|| O. H. Hershey: The Quaternary of southern California. Bull. Dept. Geol. Univ. of California, vol. iii, 1902, no. 1.

tions the probable formation of a great fault along the northern front of the chain at about the opening of the Quaternary era.

AGE OF THE SAN GABRIEL MOUNTAINS

There has been great divergence of opinion regarding the age of the San Gabriel mountains and their correlation with the other prominent ranges of California. Trask considered the granitic rocks of the chain as primitive, while Whitney placed their elevation as post-Cretaceous. Fairbanks, than whom no one is better qualified to speak, has this to say regarding the age of the plutonics and metamorphics of southern California: *

> "I believe that the great convulsion which upheaved and metamorphosed the older rocks and intruded granite into them took place as it did in central and northern California between the Cretaceous and the Jurassic. There is no break in the line of granites and crystalline schists the whole length of California."

It appears quite probable, however, in the light of some recently obtained evidence, that at least the greater part of the elevation of the San Gabriel mountains took place during either the late Eocene or Oligocene period. Tilted strata of sandstone and shale of lower Eocene age, found at an elevation of over 5,000 feet in the vicinity of Rock creek, on the northern face of the range, show that the chain has been elevated at least 5,000 feet since the deposition of the lower Eocene.† It has also recently been discovered that the conformable series of conglomerates, sandstones, and shales which flank the San Rafael hills on the south and underlie the southern portion of the city of Pasadena are of Miocene age.‡ As the conglomerates of this formation (for which the name Pasadena is here proposed) rest on and are composed of the San Gabriel plutonics and metamorphics, it is evident that the chain is certainly pre-Miocene, although quite a little elevation has taken place since the deposition of this Miocene formation.

GENERAL CHARACTER OF THE ROCKS

The following rocks have been found by the writers in the San Gabriel mountains and are described in this paper: Biotite-granite, quartz-mon-

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* H. W. Fairbanks: Geology of San Diego county; also a portion of Orange and San Bernardino counties. Eleventh Ann. Report of the California State Mineralogist, 1903, p. 119.

† Fossils from Rock creek recently sent by Dr W. C. Mendenhall to Doctor Dall for determination proved to be of lower Eocene (probably Martinez) age.

‡ The senior author and his father, Delos Arnold, have recently obtained a good series of fossils from Raymond hill, Pasadena, which proves the age of this formation to be either lower or middle Miocene.

zonite, granodiorite, hornblendite, aplite, micropegmatite, quartz-hornblende-porphyrite, diabase-porphyry, hornblende-diorite-gneiss, biotite-granite-gneiss, hornblende-schist, and garnetiferous schist.

The Sierra Madre range consists essentially of granodiorites and gneisses, with more acid areas in which the country rock is quartz-monzonite. Large dikes or included masses of hornblendite are present at several localities, notably on the south slopes of mount Lowe, while at other places smaller dikes of quartz-hornblende-porphyrite and diabase porphyry cut the country rock. Aplite dikes and quartz veins are of common occurrence, some of the latter yielding traces of gold and silver. Garnet-bearing and hornblende schists are also found in the southern range.

The character of the rocks of the mountain area north of the Sierra Madre is considerably different from that of the latter. True biotite-granite and rather coarse grained granodiorite, decidedly different in physical appearance from that of the south range, are found in the northern mass. Aplite and micropegmatite are also found in the latter region.

Taking the San Gabriel mountains as a unit, therefore, it is found that the southern border is composed principally of fine grained granodiorites and gneisses, while the central portion (the extreme northern border of the mountains was not examined by the writers) is composed of relatively coarser grained rocks, which are probably somewhat more acid in average composition than the border range types.

DETAILED PETROGRAPHY

PLUTONIC ROCKS

General characteristics.—The plutonic rocks found include biotite-granite, quartz-monzonite, granodiorite, and hornblendite. With the exception of the latter, all of the rocks of this class are gray colored and fine grained, and all, without exception, are prone to fall an easy prey to the destructive forces of weathering. The outcrops as a rule show rounded outlines, and in many instances huge detached boulders, the products of weathering, are found on the nude surfaces of the country rock. On account of the susceptibility of these plutonics to the weatherwing process, fresh specimens were hard to obtain, and the determination of the rock, even when examined in thin sections, was often more or less uncertain.

Biotite-granite.—The paucity of true granites in the territory under discussion is rather remarkable when the size of the area and the general character of its rocks is considered. Similar conditions, however, prevail in large areas of the Sierra Nevada, so that possibly this is the normal condition for the ranges of this part of the continent. The most characteristic granite area is in the vicinity of mount Waterman, and three rocks of this type from that locality will be described.

A mass of biotite-granite occurs in Chillao canyon, several miles west of mount Waterman. Megascopically this rock (A. M. S. number 15) is light brown, fine grained, and is distinguishable from most of the rocks of the region by the paucity of the ferromagnesian minerals. Its peculiar rusty color is caused by the weathering of small amounts of the biotite. Although the rock is unusually fresh, thin sections show it to be much crushed. It is hypidiomorphic granular in structure, and consists essentially of orthoclase and quartz, although well developed crystals of plagioclase are not uncommon. Some of the orthoclase crystals are much broken and show weathering slightly along the joint planes. Biotite is found sparingly throughout the rock and a little muscovite is also present as a secondary product in some of the orthoclases.

Biotite-granite, much richer in biotite than the one just described, is found at Fern camp, in Buckhorn canyon, near mount Waterman. The rock at this camp appears to be finer grained and less weathered than in most other places along the canyon, but in other respects is quite similar to the common facies. Hand specimens of this granite (A. M. S. number 19) are dark gray in appearance and show feldspar, quartz, and much biotite. Microscopically the rock is interesting on account of the microcline which is characteristically developed in it. Intergrowths of this mineral and quartz were noted. The orthoclase and microcline together are in excess of the plagioclase, although there is nearly as much plagioclase as orthoclase alone. One crystal of plagioclase shows every alternate albite twin completely kaolinized, while the intervening ones are unaltered. Epidote is the principal weathering product of the feldspars. The biotite, which is present in considerable quantities, shows brown to greenish pleochroism. Magnetite also occurs sparingly.

Another large mass of granite is found on the northeastern face of mount Waterman. This rock (A. M. S. number 22) is medium grained, gray, and shows feldspar, quartz, biotite, and hornblende. In thin sections the rock is seen to be hypidiomorphic granular. Orthoclase, apparently the dominant mineral, occurs in prominent xenomorphic crystals, through which pass parallel microscopic veinlets of kaolin and possibly muscovite. Zonal structure is common, the weathering following the zonal lines and producing kaolin, muscovite, and epidote. Occasional crystals of microcline are also present. The plagioclases are next in abundance to the orthoclase, and were determined to be oligoclase in most instances. Quartz is abundant as small grains. Some brown biotite is present, but is often partially weathered into chlorite, epidote, or muscovite. Green hornblende in spindles and a small number of magnetite grains complete the composition of the rock.

Quartz-monzonite.—Among the specimens of plutonic rocks collected in the Sierra Madre range are three which appear to be quartz-monzonites. Although these specimens are considerably weathered and the determination of their feldspars is not as satisfactory as one would wish it to be, still the bulk of the evidence favors their classification as above.

One specimen (A. M. S. number 7) comes from the Henniger flats—Eaton canyon trail, about half a mile above the canyon. It is fine grained, dark gray in color, and shows feldspar, quartz, hornblende, and biotite. In thin sections the structure is seen to be hypidiomorphic granular, and the orthoclase appears to be slightly in excess of the plagioclase. Zonal structure and zones of minute inclusions occur in some of the orthoclase crystals. A few of the plagioclases show pericline twinning. Brown biotite, a little green hornblende, and numerous small particles of magnetite are the other constituents. This rock is characterized by the nearly equal amounts of orthoclase and plagioclase and by the xenomorphic occurrence of its minerals, very few crystal faces being developed except in the plagioclase feldspars.

A. M. S. number 30, from the flanks of mount Lowe, below Alpine tavern, is another of the quartz-monzonites. It is coarser grained than A. M. S. number 7, and contains some apatite. The plagioclase, which is slightly less abundant than the orthoclase, appears to be about equally divided between andesine and oligoclase. Specimens of this rock were compared with a granodiorite from lake Tahoe, Sierra Nevada mountains, and found to be similar in general appearance, although the Tahoe rock was somewhat coarser grained. A microscopic comparison of the two showed the Tahoe specimen to contain proportionately less biotite than A. M. S. number 30, and also showed the former to contain much more plagioclase than orthoclase.

A quartz-monzonite from the south side of mount Lowe near the summit (A. M. S. number 31) is similar to number 30, except that it contains no hornblende, less quartz, and a little microcline and muscovite. The orthoclases in number 31 are much jointed and the cracks filled with a dark colored opaque substance.

Granodiorite.—Granodiorite is by far the commonest rock in the San Gabriel mountains, at least in the region north of Pasadena. It and its associated gneisses constitute most of the Sierra Madre and are also found at many other localities throughout the mountain area under discussion. The rock consists of quartz, plagioclase (either oligoclase or andesine, or both), orthoclase, hornblende, and biotite, with titanite, zircon, magnetite, and apatite as accessories. The quartz is present in relatively small quantities, so small, in fact, as often to place these particular cases very near the true diorites. The plagioclase is always in excess of the orthoclase, but in some areas gradations toward quartz-monzonite show almost as much orthoclase as plagioclase. Hornblende is the principal ferromagnesian mineral, although biotite is often present in considerable quantities. The character of the rock varies from medium to very fine grained. In color the granodiorites range from light to dark gray, depending on the amount of the ferromagnesian minerals present. In some localities the feldspars are pink and give the rock a reddish cast when viewed from a distance. This latter condition is particularly noticeable in the granodiorites exposed along the line of the Mount Lowe railroad, in Grand canyon, and in the west wall of Eaton canyon. Two facies of the granodiorite are recognizable in these mountains, a fine, almost uniformly grained type being characteristic of the Sierre Madre or southern border range, while a somewhat coarser grained form containing large crystals of orthoclase occurs in the central mountain mass.

A typical example of the first class is the granodiorite in the vicinity of Strains camp, on the northern slope of mount Wilson. On the surface this rock is usually badly weathered and decomposed, but in some of the stream beds it is possible to find comparatively fresh exposures. The specimen here described (A. M. S. number 10) is from the lower spring near the camp. In the hand specimen the rock is medium grained and rather dark gray in color, and shows feldspar, quartz, a considerable amount of hornblende, and a few flakes of biotite. Some of the hornblende is altered to chlorite. Examined in thin sections, the plagioclases were seen to be in excess of the orthoclase, and, though considerably weathered to kaolin and occasionally to epidote, were determined to be mostly oligoclase. The orthoclase occurs in xenomorphic grains, which are somewhat larger than those of the plagioclase, and often show zonal structure and occasionally inclusions. Muscovite and kaolin are its common alteration products. The hornblende is abundant in automorphic crystals, which show dark green to brown pleochroism. Quartz occurs only sparingly in small grains. Fibrous aggregates of colorless zeolites, microscopic veins and small grains of epidote, and occasional particles of magnetite are also present in the rock. Titanite was noticed in a section of a similar granodiorite (R. A. number 7), which was found near A. M. S. number 10, but was not present in any of the thin sections of the latter.

A chemical analysis of A. M. S. number 10 follows:

Analysis of granodiorite (A. M. S. number 10) from mount Wilson, A. M. Strong, analyst

SiO_2	61.38
Al_2O_3	14.33
Fe_2O_3	7.64[*]
FeO	1.02[*]
MnO	Trace
CaO	5.42
MgO	2.98
K_2O	2.58
Na_2O	4.71
H_2O	0.13
	100.19

Granodiorites of the same general type as A. M. S. number 10, but still having minor differences, occur at several places within the territory under discussion. One of these (R. A. number 7) may be taken as characteristic of the granodiorites of the crest of the Sierra Madre range. Megascopically this rock is very light gray, fine grained, and shows the clear glassy quartz and the glossy cleavage surfaces of the feldspars. Small particles of biotite are scattered quite thickly throughout the mass, but the light colored constituents so predominate as to give it almost the appearance of aplite. A few small crystals of quartz have a greenish yellow cast, and, near the weathered surfaces, small amounts of green chlorite may be detected. When viewed microscopically the structure is seen to be hypidiomorphic granular. Plagioclase, which was determined to be oligoclase and andesine in about equal quantities, is the most abundant constituent. In this mineral the faces parallel to the twinning planes are generally perfect, while the ends of the prisms are irregular in outline. Albite twinning is common, and, in one instance, twinning according to the pericline law was seen. Inclusions of muscovite, biotite, and magnetite occur in some of the plagioclases. Orthoclase, next in order of abundance to the plagioclase, occurs usually in irregular grains, but also occasionally in automorphic crystals. Zonal structure is common, and twinning according to the Carlsbad law was noted in several crystals. One orthoclase shows inclusions of biotite,

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[*] There was undoubtedly an error in the determination of the iron, the percentage of ferric iron being altogether too high for a rock containing as much hornblende as A. M. S. number 10. Taking the total iron as 8.66 (this also being too high, as the oxidation of the ferrous iron would add weight), the calculated percentages for each oxide would be about as follows:

Fe_2O_3	2.50
FeO	6.16

orthoclase, and plagioclase. Quartz is a somewhat less important constituent than the orthoclase, is present in small grains, and is free from inclusions so far as noted. Biotite occurs quite commonly in small grains, which show the characteristic fine cleavage lines and brown to green pleochroism. Muscovite is also present in small amounts, but probably only as a secondary product. A few grains of magnetite, occasional small green hornblendes, and some chlorite are also present. A characteristic diamond-shaped crystal of titanite occurs in one of the sections.

The San Rafael hills, west of Pasadena, are largely composed of biotite-granodiorite, which in most places is much jointed and weathered. Specimens of this rock (R. A. numbers 8 and 31) appear dark gray in the hand, and are seen in thin sections to be composed principally of plagioclase, biotite, orthoclase, and quartz, named in order of relative abundance.

It is not unusual in the granodiorite areas of the Sierra Madre range to find portions of the rock mass in which the ferromagnesian minerals are relatively more abundant than in the typical facies. A specimen (R. A. number 24) from one of these segregations at the summit of mount Wilson shows biotite, plagioclase, hornblende, orthoclase, quartz, and secondary chlorite, occurring in relative abundance in the order named. The minerals are nearly all xenomorphic and their characters similar to those of A. M. S. number 10. Still another granodiorite similar to A. M. S. number 10 and R. A. number 7, but containing a large percentage of hornblende, is found at the summit of mount Lowe. The minerals composing this rock are, in order of relative abundance, plagioclase, hornblende, biotite, orthoclase, and quartz, with considerable quantities of chlorite and a little muscovite as secondary products.

An example of the second or coarser grained facies of the granodiorite is found at Pine flats, southwest of mount Waterman. It forms a band of rock about a mile in width, which has a northwesterly trend across the divide from the West fork of the San Gabriel to Alder creek. The rock is more resistant to weathering than the adjacent plutonics and forms a terrace across the face of the mountain. Hand specimens of this granodiorite (A. M. S. number 12) are gray in color and are characterized by phenocrysts of orthoclase 5 to 18 millimeters in length, which are usually twinned according to the Carlsbad law. The groundmass consists of feldspar, quartz, hornblende, and some biotite, the last sometimes being altered to chlorite. Microscopically the rock is seen to be made up principally of xenomorphic crystals of feldspar, hornblende, and quartz. The plagioclases, which appear to be about equally divided between oligoclase and andesine, are the dominating minerals. Pericline twinning is common in the oligoclase. The orthoclase, as previously mentioned, occurs principally as large phenocrysts, twinned according to the Carlsbad law. Considerable quantities of quartz are present in xenomorphic grains of various sizes. The hornblende is in irregular masses, shows green to yellowish pleochroism, extinction angles of about 20 degrees, and is often altered to epidote around the periphery. Titanite is present in small quantities in wedge-shaped crystals. Zircon, apatite, magnetite, and hematite in scattered crystals complete the mineral composition of the rock. The following is an analysis of this granodiorite:

Analysis of granodiorite (A. M. S. number 12) from Pine flats, A. M. Strong, analyst

SiO_2	64.45
TiO_2	Trace
Al_2O_3	17.18
Fe_2O_3	3.32 *
FeO	0.60 *
MnO	1.62
CaO	4.31
MgO	0.75
K_2O	2.98
Na_2O	4.24
H_2O	0.59
P_2O_5	Trace
	100.04

The granodiorites of the San Gabriel mountains appear on the average to be finer grained and to contain less quartz, titanite, and zircon than those from the Sierra Nevada range of central California, but otherwise the rocks of this class from the two regions appear to be quite similar. The granodiorites near the center of the southern California chain are more nearly like those of the Sierra Nevada than are the rocks of the same class from the outer or Sierra Madre range. This statement holds true not only of the grain and color of the rocks, but also of their chemical composition.

A comparison of the analyses given in the following table will show the chemical relations of the granodiorites from the San Gabriel and Sierra Nevada mountains.

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* See note under previous analysis concerning error in determination of iron oxides. In this case the Fe_2O_3 should be about 1.31 and the FeO 2.61.

Table of analyses of granodiorites

	I. A. M. S. number 10, mount Wilson.	II. A. M. S. number 12, Pine flats.	III. H. W. T. number 17, Sierra Nevada.	IV. W. L., Sierra Nevada.	V. Limits of variation.	VI. Average composition.
					Per cent	*Per cent*
SiO_2	61.38	64.45	63.43	65.54	59–69	65.
TiO_2	....	Trace	0.73	0.39	....	....
Al_2O_3	14.33	17.18	14.20	16.52	14–17	16.
Fe_2O_3	2.50*	1.31*	1.54	1.40	1½–2¼	1.50
FeO	6.16*	2.61*	4.56	2.49	1½–4¼	3.
MnO	Trace	1.62	0.03	0.06	....	....
BaO	....	....	0.06	....	....	....
CaO	5.42	4.31	5.51	4.88	3–6½	5.
MgO	2.98	0.75	2.35	2.52	1–2½	2.
K_2O	2.58	2.98	2.19	1.95	1–3¾	2.25
Na_2O	4.71	4.24	3.49	4.09	2½–4½	3.50
H_2O	0.13	0.59	1.65	0.59	....	....
P_2O_5	....	Trace	0.11	0.18	(Remainder 1.75)	
	100.19	100.04	99.85	100.61		100.00

*See notes under same analyses on previous pages.

I. A. M. S. number 10, mount Wilson, San Gabriel mountains, Los Angeles county. A. M. Strong, analyst.

II. A. M. S. number 12, Pine flats, San Gabriel mountains, Los Angeles county. A. M. Strong, analyst.

III. H. W. T. number 17, Smartsville area, 2 miles northeast of Bangor, Sierra Nevada mountains. W. F. Hillebrand, analyst. (H. W. Turner, 17th Annual Report U. S. Geol. Survey, pt. i, 1896, p. 724.)

IV. W. L., Sierra Nevada mountains, Lincoln, Placer county, Sacremento folio. W. F. Hillebrand, analyst. (W. Lindgren, American Journal of Science, vol. ix, April 1900, p. 273.)

V. Limits of variation for granodiorite. (W. Lindgren, loc. cit., p. 272.)

VI. Average composition of granodiorite. (W. Lindgren, ib. cit.)

Comparing the analysis of A. M. S. number 10 with Lindgren's limits of variations for granodiorite, it is seen that the Mount Wilson rock is rather low in SiO_2, but high (to excess, according to the limits given in the table) in Fe_2O_3, FeO, MgO, and Na_2O. Disregarding the latter two, which are only slightly above the limit, it is evident that the iron shows the only great discrepancy. This is accounted for partially by error in the analysis (see previous notes), but mostly, however, by the large amount of hornblende in number 10. The hornblende also accounts for the high percentage of magnesium and soda. No titanium was discovered in the analysis of number 10, and no titanite was seen in its slides, but this mineral was present in a section from another specimen of a similar granodiorite found not far from the locality of number 10, thus showing the presence of titanium in the magma from which number 10 was probably crystallized.

A. M. S. number 12, from Pine flats, appears to be a normal granodiorite, although it appears to be high in MnO and low in MgO. It contains traces of titanium and phosphoric acid, although not in as large quantities as do most of the Sierra Nevada rocks of the same class.

Hornblendite.—Hornblende-gabbro is found quite abundantly throughout the range, occurring generally as large irregular dikes or masses associated with the more acid rocks. A typical occurrence is in Rubio canyon, at the foot of the famous Mount Lowe railroad incline. The rock at this locality is nearly pure hornblende. Another characteristic hornblendite is found on the slopes of mount Waterman, on the divide between the east branch of Buckhorn canyon and Bear canyon. Specimens (A. M. S. number 24) from this area show slight alteration, are rather fine grained and greenish hued, and consist principally of hornblende. Plagioclase feldspar, in crystals much smaller than those of the hornblende, also occurs sparingly in the rock. In thin sections the most important constituent is seen to be the large crystals of hornblende, which show bluish green to yellowish green pleochroism. Calcite is the principal alteration product of the hornblende, and often replaces a large percentage of the original mineral in some of the crystals. Small numbers of considerably altered plagioclases fill the interstices between the hornblende crystals, and, in some instances, form inclusions in the latter. Epidote in small grains is an occasional constituent. A chemical analysis of this rock (A. M. S. number 24) from mount Waterman, by A. M. Strong, gives the following results:

SiO_2	49.68
Al_2O_3	12.07
Fe_2O_3	10.57 *
MnO	Trace
CaO	13.85
MgO	9.02
K_2O	1.15
Na_2O	3.31
H_2O	.56
	100.21

A piece of water-worn hornblendite from Tujunga canyon below the mouth of Alder creek is almost black in color, and in the hand specimens shows nothing but large crystals of hornblende. In thin-sections this rock is seen to be made up of large pseudomorphs of brown hornblende, each being composed of numerous very small columnar crystals, all of which are oriented with their long axes parallel to the long axis of the pseudomorph. Between the more or less continuous rows of these small crystals are strings of quartz grains. Calcite occurs abundantly throughout the rock, and the quartz and calcite are doubtless the alteration products of the mineral of which the pseudomorph is but the skeleton. Magnetite occurs quite abundantly scattered throughout the mass, and an occasional zoisite is seen. Originally there were probably some feldspars in this rock, but if so all traces of them have been lost in the process of alteration.

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* FeO determined with Fe_2O_3.

DIKE ROCKS

Occurrence limited.—With the exception of aplite, dike rocks are not of very common occurrence in the San Gabriel mountains. The basic dikes, though not the most abundant, are still the most conspicuous, for, as a rule, their dark color contrasts strongly with the lighter colored granodiorites, gneisses, etcetera, which are intruded by the dikes. Aplite, micropegmatite, quartz-porphyrite, and diabase porphyry are the dike rocks recognized by the writers in the territory examined.

Aplite.—Aplite occurs abundantly, usually in small dikes cutting the granodiorites and other plutonics. It is easily recognizable by its light color, and is generally finer grained and less decomposed than the intruded rocks.

A typical aplite dike cuts the granodiorite about a quarter of a mile below Devils gate, northwest of Pasadena. It varies from 6 inches to 2 feet in thickness, is light gray in color, and microcrystalline in structure. In thin sections the rock (R. A. number 26) is seen to be made up largely of quartz, which occurs in small, clear, xenomorphic chrystals, without inclusions. Next in importance is the orthoclase, which is generally found in clouded xenomorphic grains, but which occasionally occurs in crystals showing one or more well developed faces. Inclusions of quartz and orthoclase particles were noted in some of the larger orthoclase crystals. A small amount of plagioclase, much weathered, but showing albite twinning, is also present in the rock. This constituent appears to have crystallized earlier than the orthoclase or quartz, as its crystal faces are much better developed than those of the two latter minerals. A little biotite, showing fine cleavage and green to brown pleochroism, together with some secondary epidote and chlorite, complete the composition of the rock.

Micropegmatite.—Along the borders of the Pine Flats granodiorite area, at the head of the main branch of Pine Flats canyon, are several small dikes of micropegmatite, but the fractured condition of these dikes and of the adjacent rock area made it impossible to study their relations satisfactorily in the field. Hand specimens of the rock (A. M. S. number 13) are light colored, very fine grained, and appear quite fresh. With a pocket lens quartz, feldspar, and muscovite are distinguishable. The section shows a decided micropegmatitic structure, the intercrystallization of quartz and orthoclase in parallel positions producing the typical graphic appearance. These pegmatitic crystals are imbedded in aggregates of xenomorphic grains of quartz, orthoclase, and a small amount of plagioclase, none of which show the pegmatitic structure. Small amounts of muscovite and biotite, with occasional grains of magnetite, are also found in the groundmass. The biotite is generally altered to a brown, non-pleochroic mineral, but in some instances is changed to muscovite. Some of the latter mineral, however, may be primary in origin.

Quartz-hornblende-porphyrite.—A dike of quartz-hornblende-porphyrite is found in the Big Santa Anita canyon, about 300 yards below the main falls. It (A. M. S. number 2) is a grayish rock showing small feldspar crystals imbedded in a groundmass of feldspar and hornblende. Microscopically plagioclase is seen to be the dominant mineral. It occurs principally as rather broad, lath-shaped crystals, considerably weath ered, but appearing to have numerous small inclusions. Alteration begins in the center of each crystal, and kaolin appears to be the principal resulting product, although muscovite is occasionally present. Next in importance to the plagioclase is orthoclase, which is generally much altered to kaolin. It occurs both in automorphic and xenomorphic crystals and usually contains numerous small inclusions. The principal basic mineral is a green, weakly pleochroic pyroxene, which has undergone a process of uralitization. It occurs in rather small crystals between the larger feldspars. Hypersthene is common in small grains. The quartz occurs in small xenomorphic grains scattered throughout the groundmass. Small, slender, lath-shaped crystals of a bluish mineral are also present. Magnetite is common, and pyrite and ilmenite are also present in lesser quantities. Apatite occurs sparingly in long, narrow, colorless crystals showing parallel extinction, while epidote is found in small grains.

Quartz-hornblende-porphyrite also occurs as a dike which crosses the old Sturtevant trail southeast of mount Wilson. Microscopically this rock (R. A. number 32) is gray in color and rather fine-grained in texture. It is much jointed, and fresh surfaces are hard to obtain, but where they are examined carefully they usually disclose feldspar crystals large enough to be seen by the unaided eye. In thin sections plagioclase is seen to be the most abundant mineral. It occurs in small, elongated prisms, between which are xenomorphic grains of orthoclase, hornblende, and, rarely, quartz. Inclusions are common in the plagioclase crystals, and twinning according to the Carlsbad law was often noticeable. The orthoclase grains show zonal structure quite commonly. Hornblende is abundant in small aggregates, showing yellowish green to light green pleochroism. Chlorite is a prominent constituent, being a secondary product of the hornblende. A little secondary muscovite is also present.

Diabase porphyry.—A dike of diabase porphyry 4 feet wide breaks through the light colored granite rock which forms the cascades in Big Santa Anita canyon near Sturtevants camp. The porphyry is more resistant to weathering than the intruded granitic mass, and, as a consequence, protrudes slightly from the bed of the stream and from the sides of the canyon. The rock appears to be affected by a series of invisible joint planes which become apparent when the rock is subjected to shock. Fracturing along these cracks takes place easily, but otherwise the rock is very hard and resistant. Hand specimens of the porphyry show it to be very dark colored, micro-crystalline, and with a few phenocrysts of feldspar scattered about in it. Fresh fractured surfaces exhibit the lustrous faces of the phenocrysts. Sections viewed microscopically show a holocrystalline groundmass of small lath-shaped crystals and irregular grains or pseudomorphs of chlorite, the latter being the alteration product of pyroxenes. Phenocrysts of orthoclase, plagioclase, and rarely of pyroxenes are scattered throughout the groundmass. Inclusions are common in the feldspar phenocrysts, one case in particular being noted where a single orthoclase contained a C-shaped mass of chlorite and an isolated mass of unaltered enstatite.

METAMORPHIC ROCKS

In general.—As previously mentioned, metamorphics play an important part in the composition of the Sierra Madre or border range of the San Gabriel mountains. The gneisses are by far the commonest type in this class of rocks, but schists are also present, though in less abundance than the gneisses. The following metamorphics were obtained in the territory: Hornblende-diorite-gneiss, biotite-granite-gneiss, hornblende-schist, and garnetiferous schist.

Hornblende-diorite-gneiss.—Gneisses of this type are probably the commonest rock in the southern range, with the exception of the granodiorite. They are intimately associated with the granitic facies and are probably derived from the latter by shearing stresses. They are generally fine grained, distinctly banded in light and dark, and with the banding irregularly and intricately contorted. A typical example of hornblende-diorite-gneiss is found in the west wall at the mouth of the Big Santa Anita canyon. Megascopically the rock (A. M. S. number 4) is fine grained, distinctly colored in light and dark bands, and shows quartz, feldspar and hornblende. The bands are not continuous, but are in strips varying from one-fourth to one-half inch (5 millimeters to 10 millimeters) in width and from 2 to 12 inches (5 centimeters to 30 centimeters) in length. The dark coloration is caused by hornblende. Under the microscope the gneiss is seen to consist of fine, xenomorphic crystals of plagioclase, orthoclase, and quartz in relative abundance in the order named. The feldspars are more or less fractured and weathered, calcite resulting from the alteration of the plagioclase and traversing the rock in small veins. The hornblende occurs in varying proportions, being quite abundant in the dark bands. It is the green variety, and is present both as grains and in spindles having their long axes parallel to the banding planes. The fracturing so apparent in the feldspars is not present in the hornblende. Chlorite results from the alteration of the hornblende. Magnetite in grains is also abundant, being arranged in rows in more or less regular fashion parallel to the banding. A chemical analysis of this hornblende-diorite-gneiss (A. M. S. number 4) from Big Santa Anita canyon, by A. M. Strong, gives the following results:

SiO_2	62.41
Al_2O_3	13.91
Fe_2O_3	9.87*
CaO	3.15
MgO	2.22
K_2O	3.19
Na_2O	3.34
H_2O	2.57
	100.66

A transition from hornblende-diorite-gneiss to quartz-monzonite takes place along the Henniger Flats–Eaton Canyon trail. A gneiss very similar to A. M. S. number 4 occurs in the bed of the canyon at the foot of the trail, while 200 yards up the trail, and covering the top of a small ridge over which the trail passes, is another gneiss (A. M. S. number 8). This latter differs from that in the canyon by having much larger crystals of hornblende, all of which are oriented with their longest axes in a certain direction, but which show no regularity of arrangement (or banding) in the direction perpendicular to the long axes. This irregular distribution of the oriented crystals gives the rock a very peculiar and characteristic spotted appearance. Still farther up the trail from No. 8, and grading imperceptibly into it, is the quartz-monzonite described as A. M. S. number 8. Transitions similar to the one just described are rather common throughout the range, and often take place within relatively short distances.

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*The iron was all determined as Fe_2O_3, no separation of FeO being made. This makes the total iron given a little higher than the true amount.

A hornblende-gneiss (R. A. number 9), having about equal amounts of orthoclase, plagioclase, and hornblende, makes up a large area on the Sierra Madre–Mount Wilson trail, a short distance above the Half-way house. The orthoclase in this rock shows zonal structure and, in several cases, twinning according to the Carlsbad law. Quartz, epidote, chlorite, magnetite, and hematite are also present in relative abundance in the order named. Nearly all of the minerals, especially the feldspars, are clouded by rows of minute inclusions.

Biotite-granite-gneiss.—The walls of the canyon leading back from Alpine tavern toward the summit of mount Lowe are composed of an intricately contorted banded gneiss. Megascopically this rock (R. A. number 4) is rather dark colored, the darker bands having a somewhat glossy appearance along the planes of schistosity, caused by the minute flakes of biotite, which megascopically appear to be the dominant mineral. Under the microscope, however, the principal constituent of the rock is seen to be orthoclase feldspar instead of biotite. This feldspar occurs in xenomorphic grains, some of which are quite large. Rows of inclusions parallel to the lines of schistosity pass through the feldspars and occasionally through the quartzes. No twinning is noticeable in the orthoclase, but occasional examples of zonal structure are seen. Biotite is next in order of abundance to the orthoclase, although, as previously mentioned, it appears in the hand specimen to be the dominant mineral. It occurs in small reddish brown flakes scattered among the feldspars and shows pleochroism from yellow to green. One case of twinning was noticeable in the biotite. Following the biotite in relative abundance is quartz, which occurs in small xenomorphic grains. A small amount of plagioclase (oligoclase), a few elongated crystals of hornblende containing rows of inclusions, some epidote, magnetite, zircon, and a little chlorite are also present. The sections are crossed by minute cracks approximately parallel to each other, but perpendicular to the banding. The feldspars are noticeably more kaolinized along these cracks, but the latter appear to have no relation to the cleavage, as the same crack may extend through a feldspar and an adjacent quartz or hornblende crystal. These cracks are probably due to stresses which acted perpendicular in direction to those producing the original banding of the gneiss, and which took place after the crystals had become completely formed.

Hornblende-schist.—Hornblende-schist makes up a considerable area at the foot of the Mount Wilson trail, at Sierra Madre. It occurs in thick layers and is dark green in color. Hand specimens of the rock (R. A. number 28) show it to be fine grained, but with no apparent lines of schistosity, although the lines are easily distinguishable in large masses in place. The schist is weathered on the surface to chlorite, which also coats the faces of the numerous joint cracks; but small crystals of feldspar are abundant enough in places to give it a decidedly speckled appearance. Under the microscope hornblende is seen to be the principal constituent. This mineral is present in small grains, elongated fibrous blades, and elongated prisms with frayed ends (shown in sections parallel to the long axis). Pleochroism is from light green to blue, and light yellowish brown to blue and green. Most of the crystals show the characteristic cleavage lines, but a few were noticed which showed no cleavage whatever. The usual alteration products are present in abundance. Orthoclase is not uncommon, occurring in small xenomorphic grains, which are often clouded by minute inclusions. Crystals of plagioclase are also occasionally present.

Garnetiferous schist.—A large boulder of a dark-gray garnet-bearing schist was found in the Eaton Canyon wash about a mile below the mouth of the canyon. The garnets, which were abundant throughout the rock, ranged in size from minute dots to five-eighths of an inch (16 millimeters) in diameter. No sections of this rock were made. Garnets an inch in diameter are reported as having been found in rock in place in Eaton canyon, but, with the exception of the boulder noted above, no garnetiferous rocks were found in this territory by the writers.

Summary

The San Gabriel mountains, comprising an area of about 1,200 square miles, extend for approximately 60 miles in a west-northwesterly direction from Cajon pass, in San Bernardino county, to the Santa Clara river, in Los Angeles county. Considerable divergence of opinion regarding the age of the chain has prevailed among previous writers, but it is probable that it received at least the greater part of its elevation during late Eocene or Oligocene time.

The southern range of the chain, the Sierra Madre, is composed principally of granodiorite and gneiss, with some associated quartz-monzonite and gabbro and intruded aplite, quartz-hornblende-porphyrite and diabase porphyry. The central portion of the mountains consists of somewhat coarser grained granites and granodiorites, with intruded aplite, micropegmatite, etcetera.

The granites described are of the biotite variety and are found in the central part of the chain. The granodiorites consist of two facies, a fine grained hornblende-bearing variety from the Sierra Madre or southern border range and a somewhat coarser grained variety, containing porphyritic orthoclase, from the central mass. These granodiorites differ from those found in the Sierra Nevada of central California by being, on the average, finer grained and having less quartz, titanite, and zircon. Hornblendite, consisting mostly of hornblende, but also containing a little plagioclase, is found throughout the whole area. Aplite is found over the whole region, while micropegmatite was found only in the vicinity of Pine flats. Quartz-hornblende-porphyrite and diabase porphyry occur in dikes in the southern range. Of the metamorphic rocks hornblende-diorite-gneiss is by far the commonest. Together with some biotite-granite-gneiss, it is associated with the granodiorites and quartz-monzonites of the Sierra Madre. Hornblende-schist and garnetiferous schist, found by the writers only in the southern range, complete the list of crystalline rocks described.

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EFFECT OF CLIFF EROSION ON FORM OF CONTACT SURFACES

BY N. M. FENNEMAN

(Read before the Society December 30, 1904)

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THE AREA STUDIED

The occasion of this study was an attempt to determine the relations of the Wyoming Red beds to the underlying granite in the Front range of the Rocky mountains in northern Colorado. The southern half of the Boulder and the northern part of the Denver quadrangles represent the area of investigation.

OBSERVATIONS IN THE FIELD

It was evident from the nature of the variations in thickness of the sandstones that the sediments were laid down on a submerging land surface of considerable relief. It was also apparent that the details of this relief were totally unlike the forms produced by stream erosion. The rocks immediately below the contact surface are as free from weathering as those which lie hundreds of feet lower. It is therefore evident that during the progress of the submergence of the granite land surface, shore erosion by the advancing waters has removed a part of the original land surface and altered, or rather erased, the details of relief. It was for the more exact interpretation of the forms as seen at this place that the following elementary formulation of certain general principles was undertaken.

Effect of preexisting Topography

When an eroded land surface is submerged and covered by later sediments the surface of contact between the two formations may be expected to have some dependence on the topography of the preexisting land. Other factors being equal, a topography of steep hills and valleys will show itself after burial in a corresponding unevenness of the surface of unconformity. The surface of contact is, of course, not visible, but a section of it appears when the formations at the line of contact are uplifted and eroded. If the outcrop be on a plane surface and the line of contact straight, the surface of contact is supposably a plane. There is, then, a suggestion, at least, that the land surface of the lower formation before submergence and burial was one of faint relief. The more the line of contact deviates from straightness (ignoring subsequent folding) the greater the presumption in favor of strong relief before submergence. These inferences very properly take into account the effect of the topography of a submerging land on the form of the surface of contact with later formations, but they leave out of consideration the important change which may accompany the advance of the sea.

Factors and Conditions of the Problem

There are two factors which determine the deviation of the surface of contact from a plane. These factors are (1) the form of the preexisting land surface, and (2) the strength of shore erosion during submergence. These elements may combine in any proportion. Hypothetically, two extreme suppositions may be made. The extreme of rapid subsidence and small wave erosion would result in leaving the original subaerial topography unaltered and retaining it as the surface of unconformable contact. At the other extreme is the complete dominance of shore erosion, whose tendency is to plane off the hills and to make the contact with the newer sediments a horizontal plane.

It should be stated here, though somewhat parenthetically, that shore erosion may, under certain circumstances, increase instead of destroy the relief of a submerging land surface, but such conditions are exceptional. This is apparent when it is remembered that the shoreline is a contour line; that whatever straightens the contours is bringing the surface nearer to a plane, and that the general tendency of shorelines is to straighten themselves; hence to reduce relief. The possibility of the opposite effect depends on unequal strength of the shore rocks, and can occur only when wave erosion is cutting out bays in the weaker rocks of a rugged coast, thereby making the coastline more irregular. Even under these conditions of unequal strength of rocks, increase of relief is not universal. In the following discussion this phase of marine denudation will not be considered.

There is one further exceptional and unusual case which will not be considered in the paragraphs to follow. That is the case in which no erosive work whatever is performed by the oncoming waters. This may be exemplified by a preexisting land surface of such gentle seaward slope as to require the construction of offshore barriers in order to steepen the beach profile. But even in this case observation may sometimes detect a small degree of cliff-cutting along the new shoreline before the barrier appears. The usual case, and the only one needing consideration here, is that in which submergence is attended by the paring down of hilltops.

Subsidence alone causes the shore to shift landward at a rate determined by the slope of the land and the rapidity of crustal movement. This change of position of the shoreline will be spoken of as *shifting*. But the actual migration of the shoreline will depend partly on this horizontal shifting and partly on the rate of the attendant cliff-cutting. The actual rate at which the cliffs recede and the shoreline migrates may be greater or less than this shifting. The total movement of the shoreline, regardless of causes, will be spoken of as *migration*.

If the position of the water-level be newly assumed against an irregular land surface, the first cliff erosion causes recession which is more rapid than the mere shifting which could be caused by any possible rate of subsidence. In other words, no supposition is allowable which would engulf an island so promptly that the waves could not etch its descending slopes. This forging ahead by cliff-cutting becomes less and less rapid as the cliffs become higher, the amount of detritus yielded by each foot of recession becomes greater, and the disposing of the waste becomes an increasingly difficult task. By continual cliff-cutting against a land sloping shoreward, the cliffs will eventually become so high and their rate of recession so slow that the latter will just equal the rate at which the shore would shift landward by submergence alone.

When high cliffs have once been developed it may happen, as explained below, that their recession over a given space will be slower than mere shifting of the shoreline over the same space would have been had no cliffs been cut. The extreme of this condition is found where a broad horizontal surface is reached by the receding cliff. Over such a surface shifting would, of course, be instantaneous if the sealevel were as high as the level of the plain. When there is a cliff separating these two levels the rate of migration of the shoreline is, of course, that of cliff recession and no more.

ILLUSTRATIVE CASES OF SUBMERGENCE CONDITIONS

IN GENERAL

The above conditions of submergence are more conveniently discussed by assuming certain cases and indicating them diagrammatically. No one case can represent the conditions during the whole history of a submergence, but the entire history and the forms resulting may best be described in terms of these cases.

CASE I. SHORE RECESSION MORE RAPID THAN SHIFTING BY SUBMERGENCE

Assume the rate of cliff recession to be constant and greater than the shifting due to subsidence. In figure 1 let *B A* represent the original land slope. *B C* is a certain assumed amount of vertical sinking. *C A* is then the amount of horizontal shifting of the shoreline corresponding to the assumed amount of sinking. *D A* is the actual amount of migration of the shoreline, due partly to cliff-cutting.

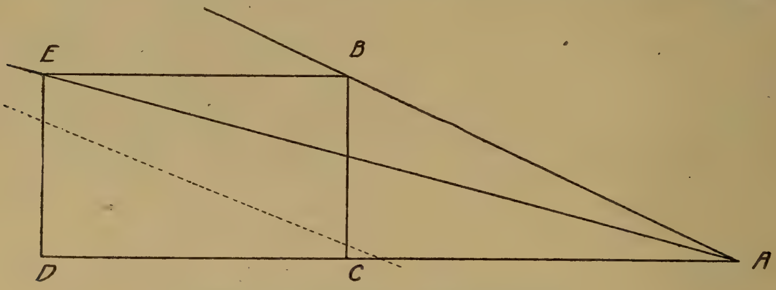


FIGURE 1.—*Recession more Rapid than Shifting.*

The tendency of the waves is to cut away the higher land and reduce it to a plane just as though there were no subsidence. In this case, however, the plane would not be horizontal, but inclined at an angle depending on the ratio of *A D* and *D E*—that is, the relative rates of cliff recession and subsidence. The water's edge, which was at the outset at *A*, advances toward *E*, and in the meantime occupies all positions along the line *A E*. This line, therefore, represents the sloping surface of a denuded bench having a gentler seaward inclination than that of the former land surface. This result is due to the fact that, on account of active cliff-cutting, the migration of the shoreline has been more rapid than shifting due to subsidence alone would have been.

The diagram represents only an initial, broad, unbroken slope of the land. If this slope be diversified by valleys and ridges, the latter will be truncated to the level of *A E*. The dotted line parallel to *B A* in the diagram, may be taken to represent the depth of the valley bottoms. As the cliff recedes it necessarily increases in height. The new-made sea bottom approaches continually nearer to the valley bottoms which at first were beneath its level in bays. The bays become smaller and fewer, the cliff more continuous; the maturity of the shore is advancing. Finally, with the extension of the plane inland, its level may fall below that of the deepest valleys, the cliff will be continuous, and the subaqueous cut terrace will have no depressions to be filled with the sediments of the newer formation. From this line landward the surface of unconformable contact between the older and newer formations will be approximately a plane regardless of initial topography.

This stage, in which denudation cuts below the valley bottoms, may or may not be reached. Cliff recession is accomplished against accumulating difficulties. Not only does the increasing height of the cliff yield an increasing measure of detritus for each foot of recession, but each cliff is becoming longer; the bays in which the shore drift was formerly stored in the form of spits, bars, and wave-built terraces, become fewer and smaller, and the material won from the cliffs must be disposed of by the slower process of dragging offshore. At any point of the line *A E* the waters may prove unequal to the task of cutting a higher cliff. They must then be content to push the shore landward at the same rate at which subsidence would shift it without cliff-cutting.

CASE II. RECESSION PROGRESSIVELY RETARDED UNTIL ITS RATE EQUALS THAT OF SHIFTING

Assume as a second case that the rate of cliff recession is progressively retarded to a minimum. If the initial ratios be taken as in case I—that is, the migration of the shoreline greater than the shifting, as defined above—then the surface of marine denudation will be begun, as before, with a lower slope than that of the land surface. However, as the rate of cliff recession is diminished it will approach that of the shifting, which it will finally equal. The surface of denudation in the meantime curves upward, as represented by the line *A E* in the diagram. When the rate of recession has become equal to that of shifting, the slope of the plane of marine denudation will equal that of the land surface. The two will be parallel and the receding cliff will have a constant height. This height will be such as to allow recession at the same rate at which the shoreline would move landward by submergence alone.

The land surface is thus pared down to a uniform depth. If this depth is greater than the former relief, the resulting cut surface will be a plane or a broadly rolling surface, as described below. This condition is represented by taking the upper of the two dotted lines in the figure to represent the depth of valley bottoms. If the depth of paring be less than that of the valley bottoms (which may then be represented by the lower dotted line), the valley bottoms will escape the paring process and their lower parts will continue to indent the denuded surface. The diminution of relief will, of course, be equal to the constant cliff height.

In general, if denudation cuts below the valley bottoms, the entire surface of the cut terrace will be of fresh rock. If erosion fail to cut so low, the valleys will be filled, and the weathered rocks of the valley bottoms will thus be preserved on the lower side of the contact.

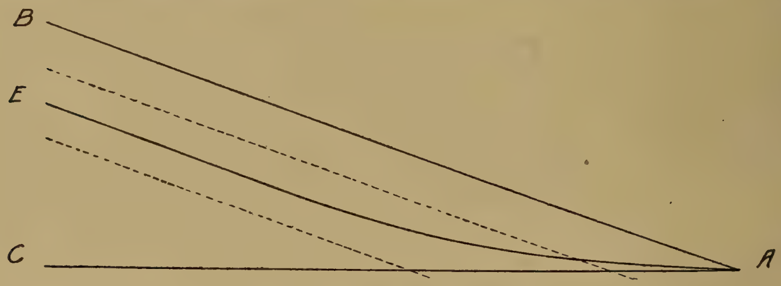


FIGURE 2.—*Recession retarded.*

Under the conditions of case II the maturity of the shoreline will at first be advanced, but a limit of development will be reached, at which the rejuvenating effects of submergence will balance the advancement in the cycle due to erosion. If the down-cutting does not extend to the valley bottoms, there will be on the site of each headland a cut terrace whose surface will, in the main, be a plane; but the sites of the valleys, and therefore of the bays, will show depressions in the older formation, filled by sediments of the newer. If marine denudation cuts below the valley bottoms, cliffs along the shoreline will be continuous, and (with one important modification, given below) the old land surface is planed down to a level.

The modification necessary to the general statement that when cliffs are entirely continuous along a sinking coast the cut terrace thus produced has a plane surface, may be stated thus: In the submergence of a surface of hills and valleys the coastline can not well be straight. Low cliffs recede more rapidly than high ones; hence where the land is low the shore is pushed more rapidly landward. Reentrant curves are thus produced, whose possible depth is limited by several factors. In general, the advancing waters have an advantage on the headlands because of their exposure, and a corresponding advantage in the bay heads because the cliff there is lower. The shape of the shore tends to adapt itself by a suitable curvature, so that these two advantages shall be in equilibrium. Within limits, therefore, cliff-cutting may be entirely continuous along a sinuous shoreline. Since the form of the shoreline at any one time is a type of the contour lines on the surface of the cut terrace, in the case in hand the terrace has a fluted surface with low ridges running seaward along the line of retreat of each headland.

It is especially to be noted that the rock surface of such a cut terrace will be unweathered. The sediments laid on it, being derived partly from the cliffs and partly from active streams, may be of the coarsest sort and may be quite fresh even when feldspathic. Both these conditions clearly distinguish this case from the advance of the sea over a peneplain with its deeply disintegrated rocks. In the latter case the sediments can be coarse only when the mantle rock of the peneplain contains peculiarly resistant pebbles.

APPLICATION OF CASE II TO THE AREA STUDIED

In the area defined in the opening paragraph the contact of the Archean granite and Wyoming sandstone presents the features appropriate to that phase of case II. in which denudation by cliff-cutting has cut beneath the valley bottoms of the submerging land. Ignoring the subsequent folding which made the Boulder arch, and supposing the eastward tilting due to mountain-making to be undone, the surface of the Archean-Wyoming contact has a maximum relief of perhaps 500 feet. Its undulations are of the smoothest sort, showing no slopes less than 3 miles long, with a maximum steepness of about 150 feet to the mile. These long slopes are entirely unbroken by valleys in the Archean floor, and the rocks of the latter are quite as fresh at the contact as at any greater depth. These features indicate that wave erosion by the advancing Wyoming sea pared the entire surface, even the valley bottoms, to a depth at least equal to the thickness of the zone of weathering; that in so doing the minor features of relief were erased and the major features considerably reduced. Cliff-cutting was therefore substantially continuous along the whole of the curved shoreline, and the sinking of the land was slow enough to admit of a mature shoreline topography during the stage recorded in the present outcrops.

CASE III. RECESSION LESS RAPID THAN SHIFTING BY SUBMERGENCE

Assume, as a third case, that the rate of migration is less than shifting by submergence alone would produce. On this supposition the surface of denudation will have a steeper slope than that of the land. This is impossible unless an initial cliff be assumed. This case therefore becomes important only as a later stage of a process begun under other conditions.

In the diagram, *B C* represent a cliff whose recession has become less than the simple shifting of the sinking shore would be without a cliff. The recession is equal to *CD* during a vertical subsidence equal to *D E*. During the same subsidence the shifting of the shore with no cliffs would have carried the water's edge from *A* to *E* through a horizontal distance equal to *D A*.

Here, again, cliff-cutting is assumed to continue at a uniform rate; hence the cut slope is a plane, and the cliff height has been reduced to zero at *E*. In actual occurrence the rate is accelerated as the height is reduced, and the line *C E* becomes a curve, convex upward and never actually intersecting the line *A B* so long as any land remains above water. Assuming the conditions of this case after cliffs have once been developed, the surface of the cut terrace will rise landward, intersecting first the deeper valleys and then the shallower, resulting in the greater separation and subdivision of headlands and the isolation of islands. The rejuvenating effects of sinking are more rapid than advancement in the cycle of erosion, and the features of maturity give way again to those of youth.

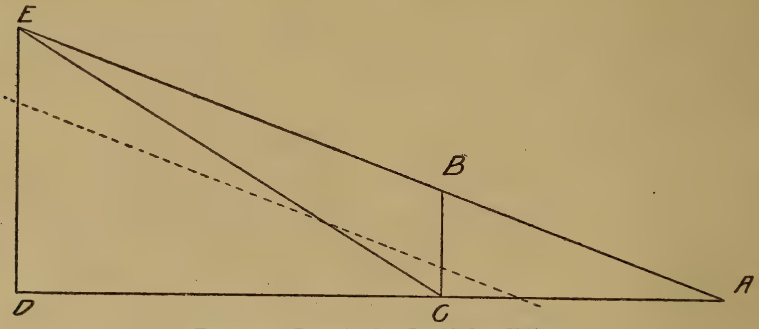


FIGURE 3.—*Recession less Rapid than Shifting.*

GENERALIZATION

Abandoning straight lines, but using the principles stated above, a truer picture of the forms actually resulting from submergence may be obtained by assuming land forms of familiar type. Assume, for example, a horizontal land, but having a seaward slope near the shore. Its surface may have something of the compound curve shown in figure 4.

The land is assumed to have considerable relief, and the submergence is assumed to be complete. Taking the process as a whole, the migration of the shoreline is equal to what it would be by shifting alone; but at different stages the actual migration and the hypothetical shifting have varying ratios.

If we assume the process to begin with relatively low initial cliffs (a common case), migration at first exceeds mere shifting by reason of excessive cliff recession (case I); the two curves representing the land surface and that of marine erosion separate; the latter is concave upward. With the decreasing rate of cliff-cutting there comes a stage where it merely equals the rate at which shifting alone would carry the shore landward (case II); the curves are about parallel and have their maximum separation. Then migration becomes less than the theoretical shifting by reason of the small seaward slope of the remaining land (case III); the lower curve becomes convex upward and approaches the upper.

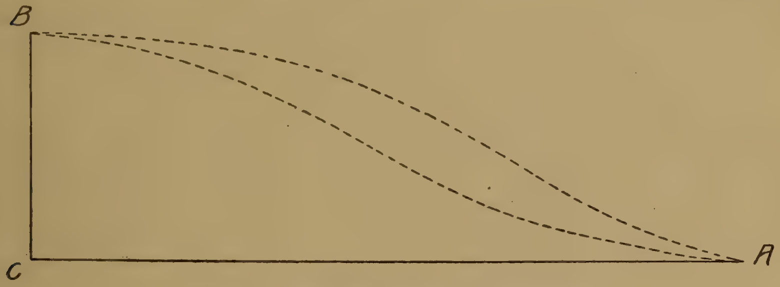


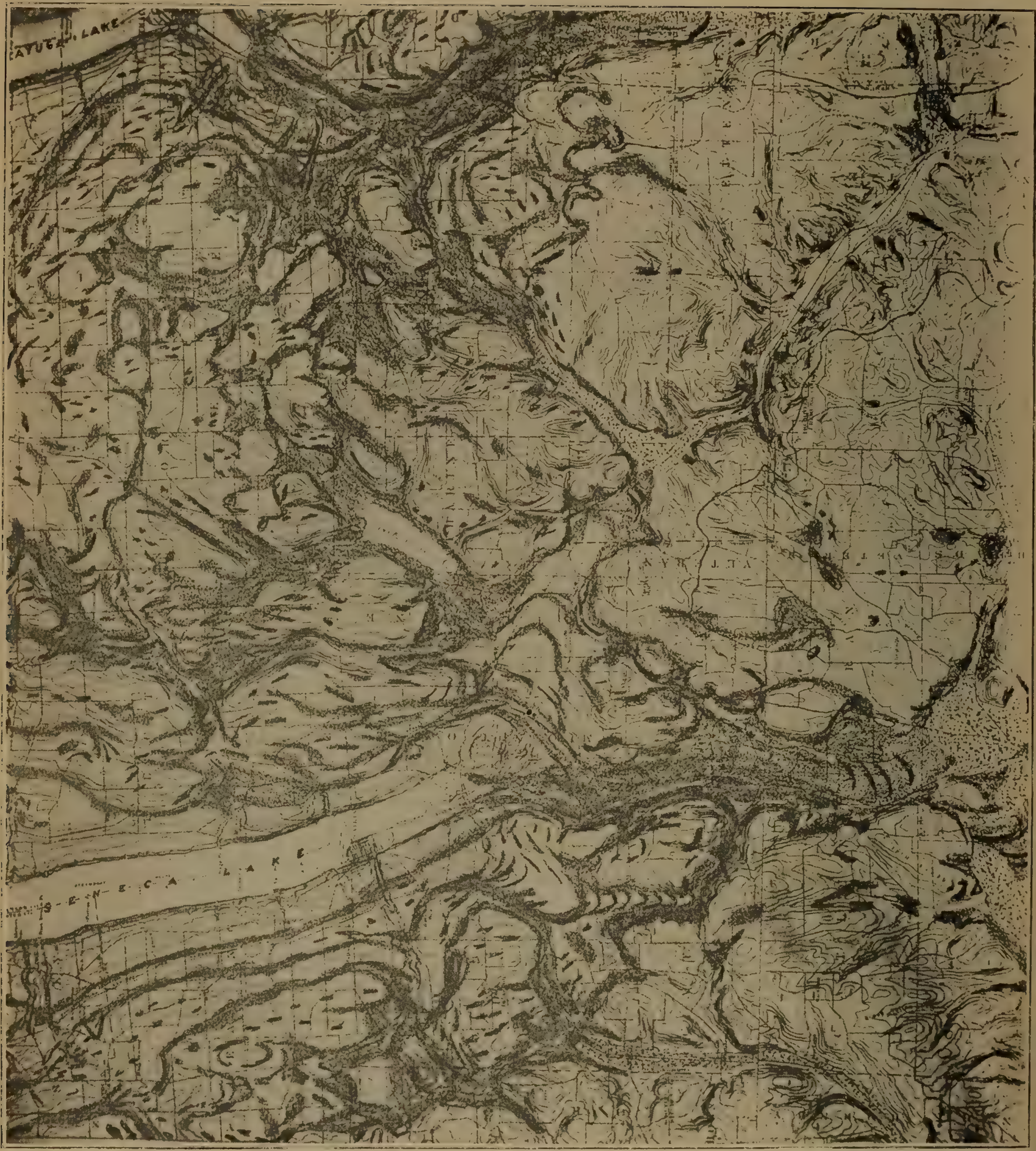
FIGURE 4.—*Generalized Diagram of Shore Erosion.*

The upper curve represents the original land surface. The lower represents the surface of marine denudation.

Interpreted in terms of shoreline topography, the erosive work of the sea at first advances the shoreline in its cycle, smoothing its contour, pushing back its cliffs rapidly, and increasing them in height and length. As this process grows slower by its own development, the effects of sinking begin to keep pace with those of erosion. The shore forms remain stationary in their cycle while the shoreline recedes landward. The cliffs have at this time their maximum height. With the diminution of slope of the land surface, the surface of marine denudation approaches it, the cliffs become lower, the rate of their recession is augmented, and the features of youth return. Continued sinking will at length cause the surface of the cut terrace to intersect that of the land, and submergence will be complete.

If the last land to be submerged were an undissected plain, it would be narrowed by cliff-cutting at an increasingly rapid rate as the height of the cliffs was lost. If the last remnant be cut by valleys, continued submergence must subdivide it into islands, the story of each one of which will reproduce, in a manner, that of the entire land mass.

In actual experience it may be expected that a large part of all cases of submergence will be found to begin with well developed cliffs cut while the land was standing still. The height of these may not be greatly increased during the migration of the coast. In such cases the initial stages of the process represented by figure 4 are omitted.


CAYUGA LAKE
SENECA LAKE

DIAGRAMMATIC REPRESENTATION OF THE DISTRIBUTION OF MORAINE AND OUTWASH GRAVEL (DOTTED) ON THE NORTHERN HALF OF THE WATKINS GLEN QUADRANGLE

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MORAINES OF THE SENECA AND CAYUGA LAKE VALLEYS*

BY RALPH S. TARR

(Read before the Society December 31, 1904)

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PREVIOUS WORK

The striking morainic development in the valleys south of Seneca and Cayuga lakes, together with some of the morainic deposits between these valleys, were observed and mapped by Professor T. C. Chamberlin as a part of the "Moraine of the second glacial epoch."† Since then no descriptions in a more detailed way have been made. For ten years the writer has been making observations on these moraines, and in 1903 undertook for the United States Geological Survey the systematic study and mapping of the moraines and other Quaternary deposits of four topographic sheets, namely, Ithaca, Watkins, Elmira, and Waverly. The results of this study will appear in the forthcoming Watkins Glen Folio, to which reference is made for local details, omitted from this generalized outline.

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*Published by permission of the Director of the U. S. Geological Survey. In the mapping of these moraines and other Quaternary deposits the author was assisted by Messrs Lawrence Martin and B. S. Butler.

†Third Annual Report U. S. Geol. Survey, 1881-1882, pp. 353-360.

General Topography

The distribution of the moraines is to such a marked extent dependent on the topography that a description of the main topographic features is necessary for an understanding of the moraines.

In general the region is a dissected plateau, with hilltops rising from 1,700 to 2,000 feet above sealevel, and valley bottoms in some cases below sealevel. The hills in the north are lower and less rugged than those in the south, so that the general upland surface slopes downward toward the north.

There are three major valleys on the Watkins Glen quadrangle—the Chemung valley, which extends east and west, and the two north-and-south valleys which, in their northern portions, are occupied by Cayuga and Seneca lakes. Between the two lake valleys, which on the quadrangle are about 18 miles apart, is a highland region of rugged topography, especially in the south, and between the lake valleys and the Chemung valley there is such an absence of marked divides that the present divides are determined by drift deposits, not by rock topography. These two north-south valleys have had a profound influence on glacial motion, and consequently on the nature and position of the morainic deposits.

Seneca and Cayuga Lake valleys are almost exact counterparts of one another. Both broaden toward the north and have less steeply rising valley walls in that direction. In both cases there is a lower steepened slope at approximately the 900-foot contour, along which there is a series of mature hanging valleys. Above the level of the hanging valleys and steepened slope the main valley walls are far less steep and more mature in form, making a broadly open upper valley, with a gorge-like trench in the bottom, whose width is about 2 miles at the top and whose depth in the Seneca valley is at least 1,400 to 1,500 feet, and in the Cayuga valley 850 feet below the level of the hanging valleys.

Direction of Ice Motion

On the uplands, away from the influence of topographic irregularities, the striæ have directions indicating a general ice movement from the northeast (north 45 degrees to 60 degrees east); but the valleys have deflected the ice in many instances. This is especially true of the Cayuga and Seneca troughs, in which the striæ are prevailingly parallel to the valley walls. Since the lake valleys have a direction somewhat west of north, these striæ indicate a deflective influence of the valley troughs, sufficient to turn the ice at a high angle from its general direction, certainly more than 45 degrees. The deflective influence proved by these striæ was, however, that exerted during the closing stages of the ice stand in the region, when the general ice sheet was thin at this point and tongues projected into the major valleys. The direction of earlier ice motion in these valleys can not now be determined, since the records were erased by the latest stands.

GENERAL HISTORY OF ICE OCCUPATION

Leaving out of consideration earlier ice advances, of which no direct evidence has been found in this region, and events connected with the *advance* of the last ice sheet, of which little evidence has been discovered, it may be stated that during the occupation by the Wisconsin ice sheet the entire area of the Watkins Glen quadrangle was covered by an ice sheet which overspread the highest hills. The outermost terminal moraine of this ice sheet is in Pennsylvania, from 45 to 50 miles south of the southern edge of the quadrangle. Although the ice stood at this outermost position long enough to build a distinct terminal moraine, its erosive activity was not sufficient to remove the decayed rock from the hills of a large part of the southern half of the quadrangle.*

From the terminal moraine northward to the New York-Pennsylvania state line the glacial deposits have not been mapped, so that it is not now certain whether the ice sheet halted during its withdrawal; but the fact that so far no moraine bands have been discovered indicates that if there were any halts they were brief. The New York-Pennsylvania state line is almost on the southern boundary of the Watkins Glen quadrangle, and from this line northward to the northern edge of the quadrangle the mapping has been in sufficient detail to warrant interpretation of the main events in the ice withdrawal.

This mapping of the glacial deposits proves that the disappearance of the ice across the southern half of the quadrangle was rapid, with no pronounced halts. No traceable moraine bands have been discovered there, and such scattered morainic deposits as are found were evidently associated in origin either with very brief halts or else with stagnant ice-block conditions. Such deposits are recognized in the Chemung valley and some of its larger tributaries.†

In the north-south Cayuga and Seneca valleys, on the other hand, there are clear records of a series of halts, together making extensive morainic deposits, often very complex in character and distribution. Between the two valleys, where the ice fronts of the several stands swung around the hilly plateau and entered into numerous smaller valleys, even more complex morainic records were left. Since the lake valleys are north-sloping, there were marginal and terminal lake conditions associated with some of the ice stands, and these were continued after the ice front had receded north of the quadrangle. Well defined deltas and extensive sheets of lake clay furnish records of these lake stages.

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* R. S. Tarr in Journal of Geology, vol. xiii, 1905, p. 160.

† These are described in the text of the Watkins Glen Folio

General Features of the Moraines

In composition the moraines vary from lake clay, till, sand, or gravel to almost every conceivable mixture of these materials. In form there is also marked variety, including sag and swell topography, kame topography, single ridges, groups of ridges, morainic terraces, and kamey ice-front contacts backed by level plains of clay or gravel, marking the sites of marginal lakes.

In distribution, as shown in plate 36, the moraines seem at first sight to be in almost inextricable confusion. This is due to the fact that during a general stand the ice lobes halted at several successive levels in a region of marked topographic irregularity. At certain levels some of the hills rose as nunataks above the ice, and lateral tongues extended from the major ice lobes into the minor valleys. There are several well defined lateral moraines, each occupying a vertical distance on the hill slope of from 40 to 100 feet, and during the formation of each of these broad lateral moraine belts the ice terminus in each of the valleys was varying horizontally in position, causing the accumulation of extensive terminal moraines. That between the lateral moraines there were briefer halts is proved by the presence of non-continuous morainic deposits and individual hummocks. These minor stands are doubtless also represented in the terminal moraines of the larger valleys, where even a brief halt made a notable record.

To make clear some of the features of the moraines it will be best to examine certain conditions in more detail.

Well defined lateral Moraines

On both sides of the Cayuga and Seneca valleys there are traceable lateral moraines at several levels; but, owing to the influence of topographic irregularity, they are less well defined on the eastern than on the western sides of these valleys. It is on the smooth slope of the western side of the Seneca valley that the lateral moraines are most typically developed, being there almost diagrammatic in their simplicity. Here there are at least five lateral moraines, which west of Watkins lie between the 960 and 1,900 foot contours. The three lower of these run straight along the smooth hill slope, while the two upper are more irregular because of the greater complexity of the topography. The two lower moraines, one on and near the 1,000-foot contour, the other about 100 feet higher, are not distinctly traceable on the more hilly eastern side of the Seneca valley, while on the western side of the Cayuga valley they are apparently merged into a single broad moraine.

Below the lower of these two moraines, on both sides of each valley, there is absolutely no development of moraine deposit. Thus while above the lowest moraine there is much moraine topography for a vertical distance of 800 to 900 feet, below it, through a vertical distance of 500 to 600 feet, there is no moraine.

The lateral moraines vary greatly in component material, from till to gravel, and in topography from hummocky kame moraine or well defined ridges to gently undulating sag and swell topography. One remarkable feature about these moraines is the low rate of inclination of the ice margin which they prove. In a distance of 9 miles, between Watkins and the northern edge of the quadrangle, the lowest moraine scarcely descends at all, and in the same distance the next higher moraine descends a little less than 200 feet. This low rate of descent of the ice margin is doubtless due to the fact that the ice tongue, backed by a great ice sheet, pushed freely up these smooth-walled valleys; and the difference in rate of descent of two neighboring, nearly parallel moraines is probably the result of the fact that at the higher stages the ice was less distinctly under the influence of the inclosing valley walls. In both cases the low rate of descent indicated by the lateral moraines contrasts strikingly with the rate at which the ice margins descended into other smaller valleys.

The higher lateral moraines are far less regular and simple, but they, too, indicate a moderate slope for the ice-tongue margins. Their lack of simplicity is explained by the fact that hills rose across the path of the ice, forming nunataks at some of the stands, while the broader valleys of the uplands caused a deflection of the ice margin up lateral valleys and in some cases across lowered divides down the open valleys.

During the highest stands of the ice the main valley tongues extended south of the present divides of Cayuga and Seneca valleys, reaching farthest south along the more open valley south of Seneca lake. North of the divides, in the bottom of each of the lake valleys, there is a maze of complex morainic topography, toward which the lateral moraines lead by a series of moraine terraces.

Frayed Moraines

On the sides of many of the valleys tributary to the Seneca and Cayuga troughs there are steeply descending ridges, sometimes composed of till, sometimes of stratified drift, and sometimes of a mixture. They vary in height, breadth, and details of form, but are most commonly distinct ridges with undulating crests not more than 20 or 30 feet high. While in some cases they have the appearance of erosional forms, as if carved out of drift by streams descending the hill slope diagonally along the margin of the ice tongues, they are more commonly evidently of constructional origin. These forms are interpreted as marginal moraines built along the side and end of minor tongues which extended from the main valley tongues into the lateral valleys. In fact, in some cases the ridges are directly continuous with lateral moraines of the main valleys from which they extend, with greatly increased slope, often descending as much as 100 or 200 feet in less than half a mile.

A lateral moraine of one of the main valleys is not represented in the side valleys by a single ridge, but by a series of diagonally descending ridges, radiating, fan-shaped, from the main valley lateral moraine. A lateral moraine whose ridges and valleys on the main valley wall occupy continuously a space of a quarter of a mile, with a vertical range of 100 feet, may, on entering a side valley, fray out into a dozen or more morainic ridges or *strands*, spread over a space of fully a mile. These frayed moraines, which where best developed resemble a rope, the strands of which are untwisted and spread apart, are found in many of the valleys of the quadrangle, and are one of the most characteristic morainic features of the area.

It is evident that the separate strands represent halts in receding tongues which extended into the lateral valleys. The distance between the strands represents the distance through which the ice front retreated horizontally during a vertical drop of a certain related number of feet on the main valley side. The ridges of which the lateral moraines of the main valley are composed are undoubtedly the correlative of the strands of the lateral valleys; but in the lateral moraines of the main valley the ridges are so close together and so interwoven that they can not be separated. How many times a foot of vertical recession in the main tongue is multiplied in the horizontal recession of the lateral tongues, as indicated by the strands, is uncertain; but it is evident that the amount varies with the width of the deflecting valley, the slope of its sides, its bottom slope, and the angle and direction of ice approach.

Moraines of lateral Tongues

Into the larger valleys tributary to the main Cayuga and Seneca troughs the ice swung so far as to destroy the distinctly frayed appearance of the morainic strands so characteristic of the smaller valleys. In such places distinct morainic bands and moraine terraces descend fairly steeply to the valley bottom, crossing it in a series of crescentic loops with hummocky and often kamey fronts, against which the ice rested.

In some cases there is a succession of these terminal moraine loops connected with the ice stands of various levels. In one case, southeast of Watkins, loops correlated respectively with 1,000-foot and 1,800-foot moraines in the Seneca valley are 6 miles apart. From this it is concluded that a vertical recession of about 800 feet in the main valley is represented in a lateral valley of this kind and position by a horizontal recession of the ice tongue of about 6 miles.

Marginal Lakes

Where such lateral tongues extended into valleys whose slope was toward the ice, each of the stands of the successive ice levels interfered with preexisting drainage, and the ice front was in standing water ponded back by the ice dam. Into these ice-dammed lakes debris was poured not merely directly from the ice, but by the marginal streams and by streams from the land which the ice no longer covered. In the area of the Watkins Glen quadrangle there is represented every gradation in the filling of such marginal lakes, proving that this condition was a common one during the various stands of the waning ice sheet.

In some cases the lake filling was completed and broad plains of outwash gravel built back of kamey ice-front moraine deposits. In such cases the valley bottom consists of a series of terrace steps, the terrace front being moraine and the successive terrace tops being determined by the different levels of lake outflow. Not uncommonly alluvial fan deposits, brought both by marginal and land streams, have raised the filled lake plains still higher. Doubtless many of these filled lake plains were partly supplied by feeding eskers, later buried beneath moraines and lake fillings of lower ice stands, but in only one place was such a condition discovered.

Unequal Development of Moraines of valley Lobes

In the lateral valleys it is almost universally the case that moraines are much better developed on one side of the valley than on the other. In one case, for example, a remarkably perfect kame moraine is present on the north side of a valley, while moraines of the same ice stand on the south side are either weakly developed sag and swell type or else morainic terraces of no great width. There is probably from 20 to 50 times more material in the moraine of the northern than of the southern side. At times this unequal morainic development is so marked that, whereas well defined morainic strands descend one of the valley walls, no traceable moraines have been detected on the opposite wall.

So widespread is this condition that it is evidently the result of the operation of a law governing morainic accumulation along the margin of valley tongues. This law seems to be that the least morainic development is on the side which has the least supply from the ice and from marginal drainage (*C–D*, figure 1). In lateral tongues it usually happens that there is one long drainage slope and one shorter one. In the case mentioned, for example, the distance from the terminus of the valley lobe to a divide where marginal drainage tributary to this valley began to accumulate is many times greater to the north (*A–B*, figure 1) than to the south (*C–D*, figure 1). The shorter marginal streams along the southern side of the valley tongue evidently did not gather enough drift for the construction of pronounced moraines, whereas the longer northern streams did.

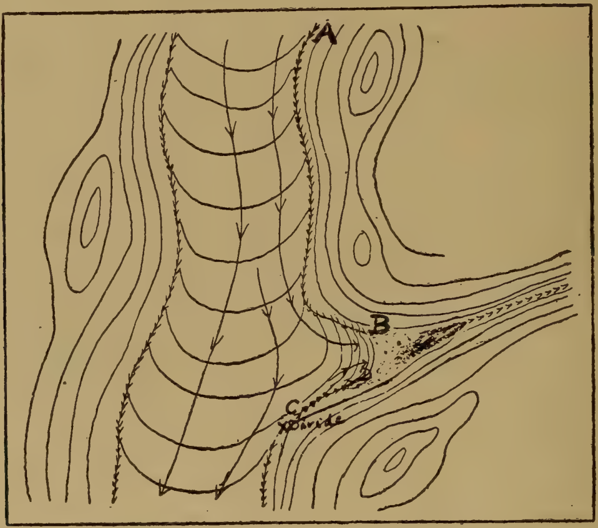

Figure 1.—*Diagram illustrating Causes of unequal Development of Moraine in lateral Ice Lobes.*

For essentially the same reason the supply brought directly by the ice and accumulated at its terminus is far greater on the side of the longer than that on the shorter side. In the case just mentioned, for example, ice movement and supply to the moraine on the northern side was really dependent on the southward movement of the marginal portion of the main valley lobe, but the ice movement and supply on the southern side was merely that of the short tongue itself supplied from the less heavily drift-filled ice away from the margin of the main valley lobe. Therefore the moraine on the northern side received large contributions from outside the valley, while that of the southern side came mainly from the material which the small lateral tongue could supply. There are doubtless instances in some localities where the supply furnished by the land streams has modified the unequal development of moraines.

Moraines distinctly traceable for a distance often lose distinctness, and even become untraceable where crossing hill slopes or hilltops at points where there were divides between two ice tongues. Where they do not entirely disappear they sometimes change in character, from kamey areas of stratified drift to low ridges and hillocks of sag and swell type composed mainly of till. These variations are doubtless due to unequal effects of marginal drainage and ice supply similar to those above described. On such ice-divide areas the influence of marginal drainage is reduced to a minimum, and the dominant, and often the sole cause for morainic accumulation is the melting out of rock fragments from the ice front.

Morainic Complex between Cayuga and Seneca Valleys

In the hilly country between Cayuga and Seneca lakes there is a morainic complex which seems to have little system. In some portions the moraine bands are traced continuously for several miles; but where crossing a valley or passing across the hills these are often lost, so that it becomes almost or quite impossible to correlate moraines on two sides of a valley.

The complexity of the conditions during the ice withdrawal from this region may be understood from the following statement: As the ice melted away the higher hilltops first appeared, and around some of them nunatak moraines were accumulated during a halt in the ice recession. These nunatak deposits are rarely continuous and are often not easy to distinguish from parts of moraine belts. A later stage found ice moving completely through valleys, while the inclosing hills rose above its level. In some of the valleys high-level moraine terraces and other moraine deposits furnish evidence of such a stage. The next step in the ice withdrawal may be considered to be that in which free movement through the valleys ceased while stagnant blocks remained. Thickened hillside deposits, often of a morainic character, present in many of the valleys and apparently not associated with active ice tongues, are interpreted as deposits marginal to such stagnant blocks.

After the stage of stagnant blocks active ice tongues extended into the valleys, sometimes from both ends. During these stages there were built frayed moraines on one valley wall, and often terminal moraines in the valley bottoms, while on the opposite side of the valley the moraines are usually either very faint or else absent. The records of these active ice tongues from opposite directions are often very clear. The distance to which they extended into the valleys of the plateau depended on the direction, slope, and width of the valley and the height and direction of approach of the main ice mass at the valley entrance.

Terminal moraine Loops

In valleys into which the active ice lobes extended and stood in one position for awhile pronounced terminal moraine loops were built. These loops vary greatly in composition, but usually contain a large percentage of assorted drift. In form they vary from terrace fronts faced by lake beds, where built in marginal lakes, to a complex of kames, ridges, and hummocks and, in some instances, single ridges 50 to 100 feet high extending part way across the valley. They are usually concave in the direction from which the ice came. Several typical instances of these loops are described in the Watkins Glen Folio.

Morainic Fans

On several valley slopes, below broadly open divides, extensive accumulations of morainic drift occur. In such cases a morainic band extends from both directions toward the divide, on the opposite side of which is a thickened drift deposit, mainly of till, deeply dissected by valleys, many of which could not have been formed by post-Glacial erosion. The thickened deposits assume a more distinctly morainic topography farther down the slope, and at the same time the percentage of stratified materials increases. Near the base of the valley slope the moraine topography is very perfect, and the material is prevailingly stratified drift.

The morainic deposits in such situations are believed to be due to the presence of hanging glacier tongues which passed over the divides when the edge of the main ice mass rested at a level just above the divides, and from which debris-laden waters escaped, both eroding and depositing. The name "morainic fan" for these deposits was suggested by Mr M. L. Fuller, who crossed one of these localities with the author.

Nunatak Moraines

During the several ice stands it frequently happened that isolated hills or groups of hills projected through the ice as nunataks, on which moraines were often accumulated. These nunatak deposits vary from till ridges to hummocky kame moraines, and they vary greatly in position. Frequently they cap the hilltops, making nunatak moraine caps, formed apparently when the hilltops barely rose above the ice. Some of these caps are single ridges, some sag and swell moraine, some merely thickened drift of slightly irregular topography.

Where the nunataks rose well above the ice sheet, moraine collars were built on the hill slopes. These nunatak moraine collars are not developed with uniform intensity throughout, but, as a general rule, thicken toward the lee side of the hill, where they form great masses, sometimes of irregular till and clay, sometimes of gravel, with kamey topography.

Morainic Complex in the upper Cayuga and Seneca Valleys

In both the Cayuga and Seneca valleys, beginning at a point 2 or 3 miles south of the lake, and extending thence southward about to the present divide, a distance of 10 or 12 miles, is a massive valley-bottom moraine whose striking development exceeds that of any other areas in the quadrangle. Since the valleys in each case slope northward and the moraines over a large part of the area are not higher than the divides to the south, it is evident that in each of the valleys the moraines were built in the standing water of a marginal lake dammed up by the valley ice tongue. Leading down to this morainic complex are a series of moraine terraces and ridges, well developed on the moderate slopes, but absent on the steeper slopes. These moraines, which are directly continuous with the lateral moraine bands previously described, are prevailingly of gravel, and often have the form of perfect moraine terraces with moderate slope, ending in abruptly descending ridges which extend out into the valley, where they become lost in the general morainic complex. These rapidly descending ridges are evidently the correlative in the main valley of the frayed moraine strands of the smaller lateral valleys.

The freer movement of the ice in these main valleys, doubtless including slight advances as well as retreats, accounts for the greater length and more striking development of moraine there. Each of the ice stands made a series of moraine deposits at its terminal portion, and even where halts were not of sufficient duration for the accumulation of lateral moraines on the valley sides, terminal deposits were undoubtedly accumulated in these major valleys. It is only on this basis that the marked continuity of the valley-bottom moraines is to be accounted for. The same explanation is advanced to account for the fact that in both valleys the valley-bottom moraine extends farther north than the point where the lowest lateral moraine descends into the valley; for on the valley sides there are no lateral moraine bands which can be correlated with the northernmost portions of the valley-bottom moraines, which are, as would be expected from this theory, much less well developed than those portions farther south to which the definite lateral moraines descend.

Borings in the moraine, which attain depths of from 100 to 400 feet, together with cuts at the surface, prove that the morainic materials in this valley-bottom complex are very variable in kind and in position. Till is revealed in some of the cuts, but the moraine is largely composed of stratified clay, sand, and gravel. Small cuts often reveal two or three different kinds of drift, and these are usually confusedly thrown together. Both faults and crumpling are frequently revealed in the cuts, proving movements subsequent to deposition. While some of the faulting is undoubtedly associated with recent slipping, most of the deformation of the layers is evidently due to conditions associated with the morainic accumulation, such as the shove of the ice tongue or of icebergs and the melting out of stranded ice blocks.

In topography there is much irregularity and usually little appearance of system. In general the moraine consists of a series of hummocks and short, irregular ridges, some of which rise fully 200 feet above the valley bottom. The overlapping of the hummocks and ridges has given rise to many kettles, some of large size, in which swamps and ponds occur where the material inclosing them is not too gravelly. Stream erosion has in places deeply dissected the unconsolidated morainic deposits, adding greatly to the topographic irregularity. By the slipping down of the sides of the small, steep-sided valleys a very perfect type of landslide topography is often caused.

The valley-bottom moraine varies in character from south to north, or between the divide and its northern edge, where it disappears beneath the modern deltas of Cayuga and Seneca lakes. It exhibits three quite different types of morainic form, most perfectly developed in the Cayuga valley. The southernmost of these is the most normal morainic type, in which the lateral moraine terraces extend into perfect terminal moraine loops. Where best developed, as on the divide south of Cayuga lake, there is a crescentic ridge, concave toward the north, and with outwash gravel terraces extending southward from each end. Near the middle the distinct ridge form disappears, being replaced by a maze of kame moraine, with many gravel hillocks and deep kettles. Just north of this are one or two less perfect terminal moraine loops. These loops were built in the air and not in lake water.

Farther north in each valley, but especially in the Cayuga valley, there is a series of broad, rather flat-topped ridges, roughly crescentic, with concave faces toward the north, and with crests reaching to a nearly uniform level. These are interpreted as the result of ice stands in a lake of sufficient duration to permit the building of the moraine to the level of the lake surface, but not to completely fill the lake and make a plain. This belt of moraine is not very broad.

North of this, and constituting the bulk of the valley moraine, is a veritable morainic jumble. Below the level of the lateral moraine terraces, which were built at levels above the marginal lake, there is almost no system in the moraine. The hummocks rise to various levels, and, while there are numerous ridges extending out into the valley, there are no distinct terminal loops. At several places, however, the morainic hodge-podge is more massive and better defined than elsewhere, doubtless because the ice fronts stood there longest; but well defined moraine occupies the entire area between these places of greater morainic development.

The irregular, indefinite form of the hummocks and ridges in the latter belt, the exceptionally large proportion of stratified clay, and the position of the deposit in a north-sloping valley, whose divide is higher than the crests of the morainic hummocks, prove that this third type of moraine is sublacustrine in origin. Its marked irregularity of structure and form, and the absence of definite terminal loops, indicate that varied and, in part, unusual conditions were involved in its formation. Among these conditions were standing water, rapidly moving water currents and eddies near the ice margin, direct dump of debris from the ice, inwash of sand and gravel from the marginal and subglacial streams, ice-shoving, the shove of grounding icebergs, and the melting out of buried ice blocks, probably both stagnant blocks and stranded bergs. Such a complex of conditions suffices to account for the jumble of moraine in this section; and the great length of the morainic area is readily understood when we consider the fact that there is represented in this valley moraine the effect of the horizontal oscillation of an ice lobe during vertical recession of several hundred feet, as registered by the hillside lateral moraines.

Mode of Formation of the Moraines

The field studies, of which the above is but a bare outline, prove conclusively that the moraines of the Watkins Glen quadrangle are prevailingly, if not uniformly, of marginal and not submarginal origin. The unequal development where marginal drainage was unequal, the presence of marginal drainage channels in the lateral moraine bands, the distinct moraine terraces and fronts with ice-contact faces, the steeply rising ridges, both in the lateral moraines and the terminal moraine loops, and the excessive kamey development of the moraine where marginal streams descended into valleys, or where land streams flowed against the ice margin, all testify to this origin. The moraines do not appear to be in any essential respect different in origin from those now accumulating as marginal deposits along the edge of the Greenland ice sheet.

Marginal and outflow Channels

Closely associated with the moraines are channels which were evidently occupied by streams marginal to the ice lobes. Besides being too large for streams now occupying them, and being very often in positions where drainage could not exist without some barrier now gone, the channels are peculiar in a variety of ways. Sometimes there is only one bank, the other having been the ice. Often the channels both begin and end abruptly, their continuation doubtless having been on the ice, and at times they terminate in gravelly deposits built of debris which streams brought through these valleys. They vary in length from a few score yards to 2 miles, and in depth from 4 or 5 feet to over 50 feet. Usually they are in drift, but some are cut partly or wholly in the bed rock. Small streams in some cases meander over the swampy bottoms of the broad, flat channels.

There are several well defined outflow channels across divides, usually across terminal moraine deposits behind which ice-dammed lakes were held. Of these the largest are the two that carried southward the waters ponded back in the Cayuga and Seneca valleys when the ice was withdrawing from these valleys. The Seneca valley overflow, known as the Horseheads outflow, which carried the waters of glacial lake Newberry, is the longest and best defined.

Outwash Gravels*

Wherever the ice stood on a grade sloping away from it, or wherever by its deposits it built up such a grade, the outwash gravels have raised and leveled the valley bottoms by building outwash gravel plains. The best and most perfect case is in the Horseheads-Elmira valley, where the major part of the gravel supply came from the main Seneca valley lobe; but a similar though less extensive outwash plain was built south of the Cayuga Lake valley. Smaller outwash gravel plains were formed in other valleys, and their position is indicated by the dotted area on the map (plate 36). In each case the outwash gravels commence at the outer base of terminal moraines either as terraces or kamey gravel hillocks; but in a very short distance they become remarkably level plains, with occasional kettles and crossed by channels of the outwash streams.

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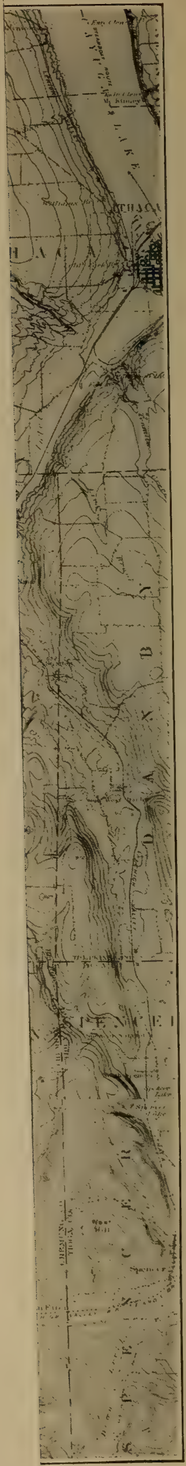
*These, together with the eskers, kames, and other Quaternary deposits, are more fully described in the Watkins Glen Folio.


LAKE
ITHACA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 16, PP. 229-242, PLS. 37-42 APRIL 29, 1905

DRAINAGE FEATURES OF CENTRAL NEW YORK*

BY RALPH S. TARR

(Read before the Society December 30, 1904)

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DESCRIPTION

INTRODUCTORY

Location of the area.—The region described in this paper is in southern central New York, along and near the divide between the Saint Lawrence

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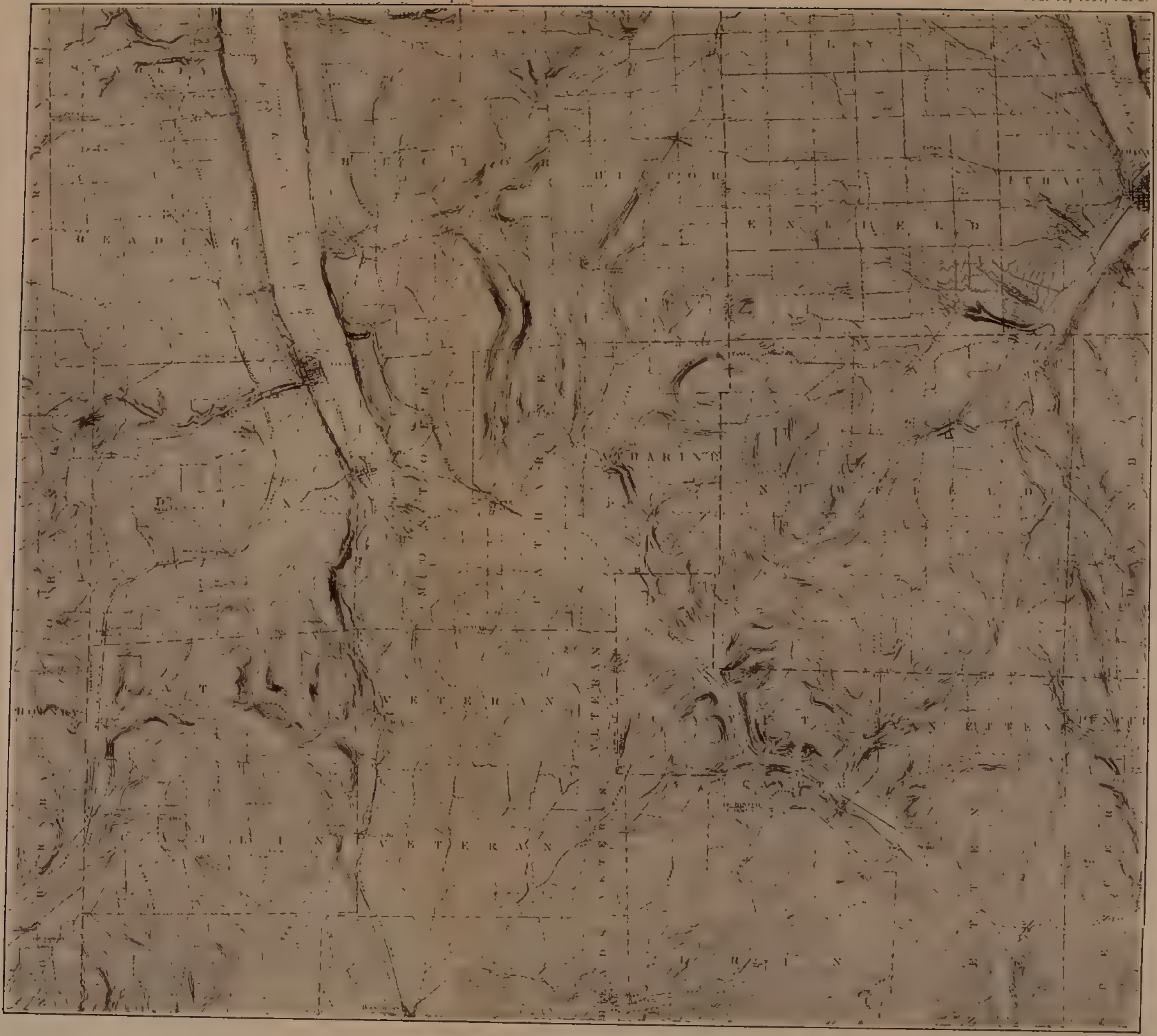
HECTOR
READING
ENFIELD
ITHACA
CATHARINE
NEWFIELD
VETERAN
VETERAN

NORTHERN PORTION OF WATKINS GLEN QUADRANGLE

and Susquehanna drainage systems. Most of the facts were obtained in studies leading to the preparation of the Watkins Glen Folio (see plate 37) of the United States Geological Survey, which includes the Ithaca, Watkins, Elmira, and Waverly topographic sheets; but some of the facts were discovered in the studies on the quadrangle east of the Watkins Glen.

*General topography.**—The area under discussion is a part of the dissected Allegheny plateau, with uplands of mature form, deeply trenched by valleys of less mature character, whose sides are often too steep for farming and in some cases even precipices. In ruggedness of topography there is a difference from south to north, the northern portion being both evener and smoother than the southern. The uplands reach elevations of from 1,800 to 2,000 feet in a number of places, and even the smaller streams are in valleys whose bottoms are several hundred feet deep. The lowest known point in the region is the rock floor of the Seneca valley, which at Watkins is at least 637 feet below sealevel.

South of the divide, for the most part near the Pennsylvania state line, there is the long, deep Chemung-Susquehanna valley, extending east and west, with the united drainage from the two directions turning southward below Waverly. This is the largest valley in the area. North of the divide are north-south valleys, two of the largest of which are occupied by Cayuga and Seneca lakes. There are numerous smaller valleys tributary to one of these three major valleys, the largest having a general north-south direction, and most of them tributary to the Susquehanna system.

HANGING VALLEYS

Hanging valleys in Cayuga and Seneca troughs.†—In both the Cayuga and Seneca valleys there is a change in valley slope at about the 900-foot contour, the lower slope being much steeper than the upper (see plate 39, figure 2). This steepened slope extends to the bottom of the valley—that is, at least 850 feet in the Cayuga valley and from 1,400 to 1,500 feet in the Seneca valley. The region near Watkins may be taken as an illustration of this change in slope. From the 900-foot contour just west of Watkins there is a slope down to the valley bottom of 1,400 feet in a little over a mile, while west of the 900-foot contour the valley side rises only 700 feet in a distance of 5 miles.

Down to approximately this same level a series of valleys descend with moderate grade from the uplands; then the valleys change to gorges

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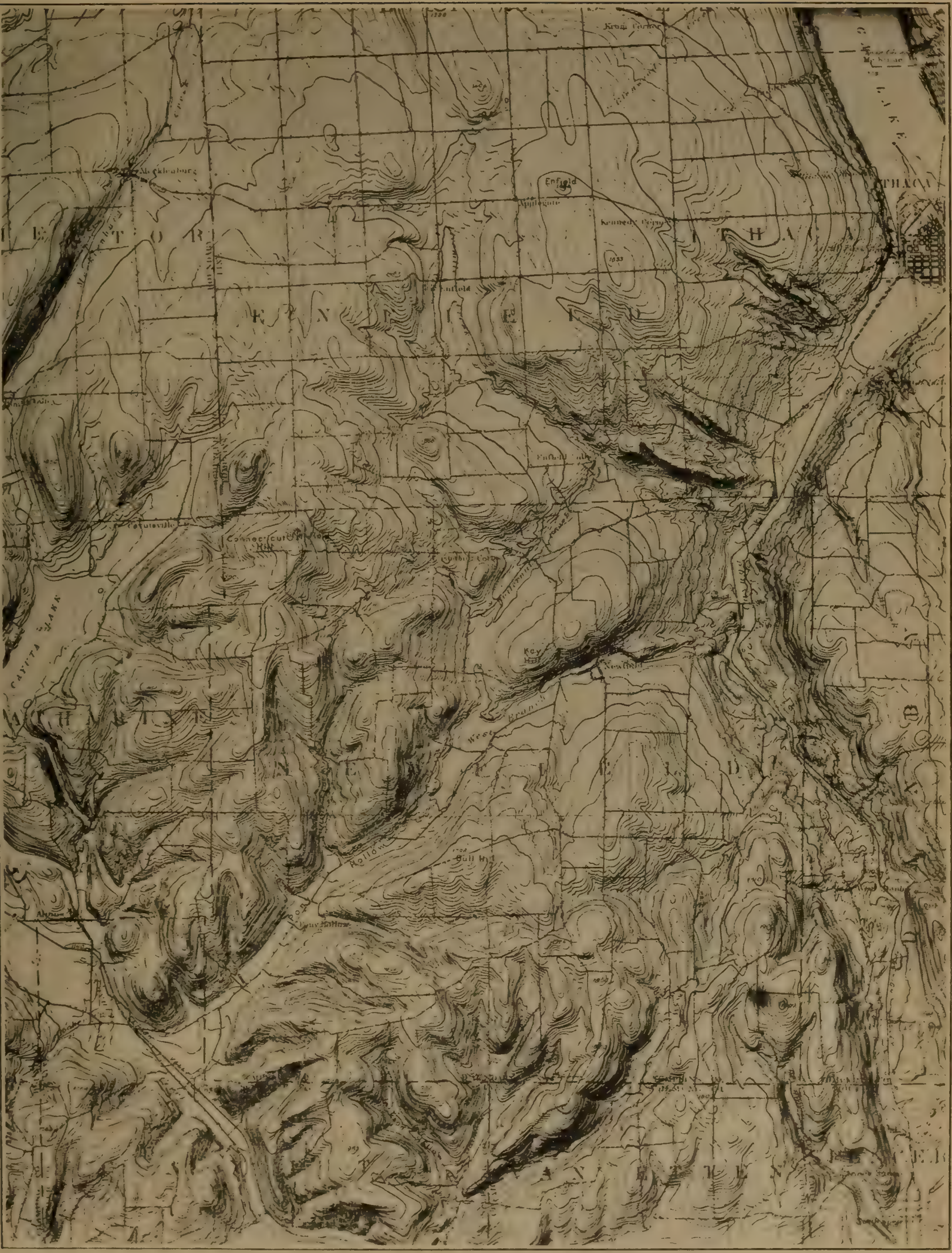
* The text of the forthcoming Watkins Glen Folio contains a fuller and more complete discussion of the topography of this region.

† R. S. Tarr: American Geologist, vol. xxxiii, 1904, pp. 271-291.


Mecklenburg
Enfield
Applegate
Kennedy Corners
ITHACA
ENFIELD
Enfield Falls
Connecticut Hill
Key Hill
Newfield
West Branch
Bull Hill
CAYUTA LAKE
NEWFIELD

ITHACA TOPOGRAPHIC SHEET

Photograph of a model (by William Stranahan) of northeastern portion of plate 37

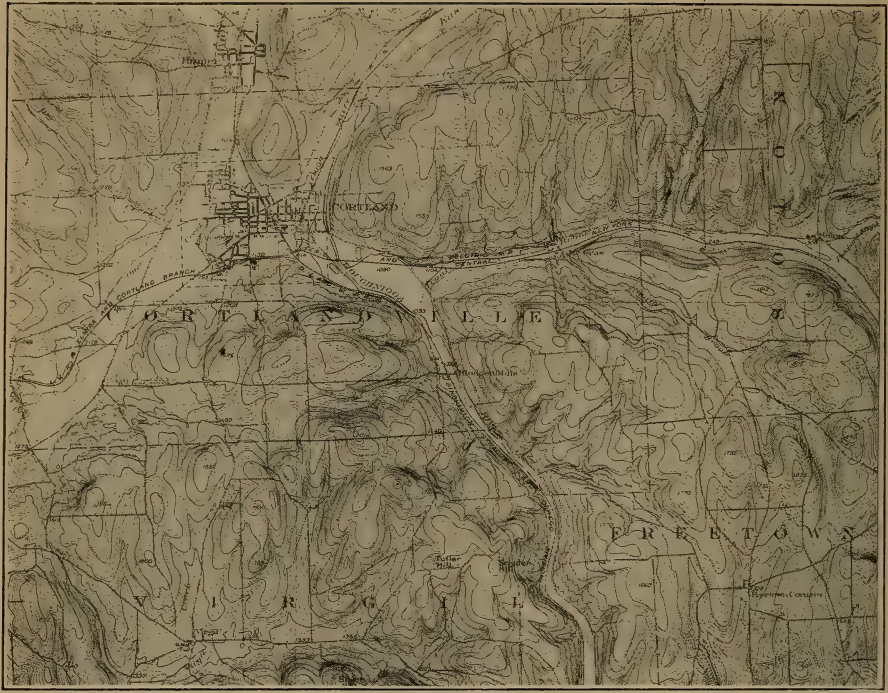

CORTLAND
CORTLANDVILLE
VIRGIL
FREETOWN
TIOUGHNIOGA
NEW YORK CENTRAL
CORTLAND BRANCH
Blodgett Mills
Fuller Hill
Snyder Hill
Freetown Corners

Figure 1.—The Diversion of the Tioughnioga River

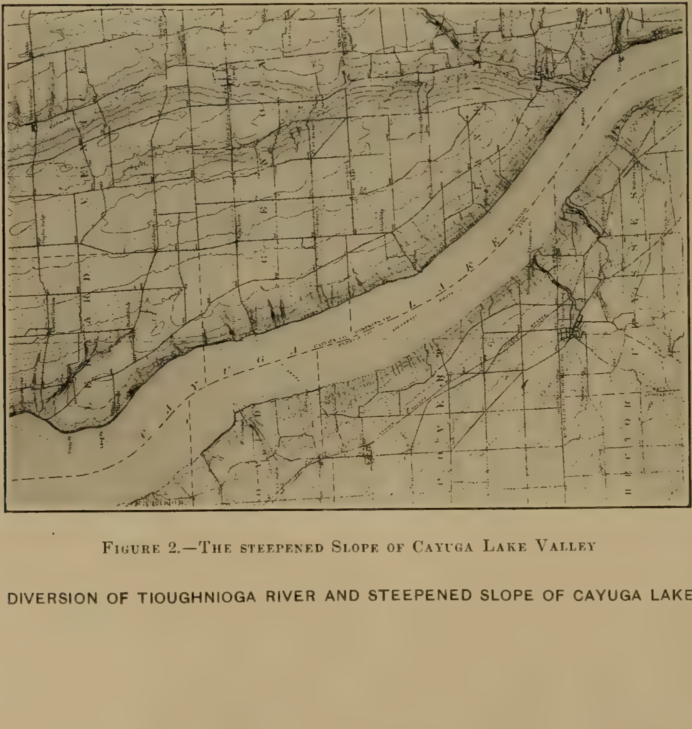

CAYUGA LAKE

Figure 2.—The steepened Slope of Cayuga Lake Valley

DIVERSION OF TIOUGHNIOGA RIVER AND STEEPENED SLOPE OF CAYUGA LAKE in which the streams tumble precipitously down the steepened slope as a series of rapids, cascades, and falls (figures 2 and 3 and plate 38). The maturity of the hanging valleys proves that a long time was required for their development at a baselevel not far from the 900-foot level. There are two ages of gorges cut in the steepened slope, one distinctly post-Glacial, the other, being both broader and deeper and partly filled with deposits made by the Wisconsin ice sheet, evidently antedating the advance of this ice sheet.

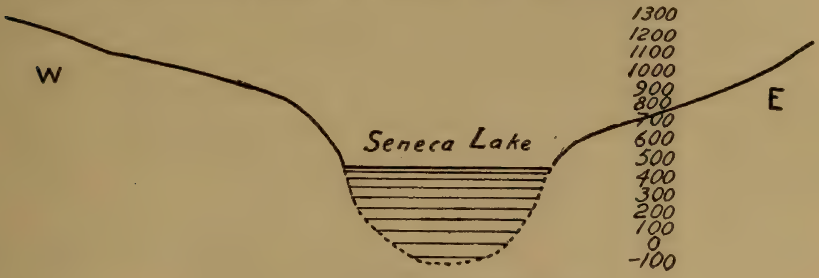

W
Seneca Lake
E
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100

FIGURE 1.—*Cross-section of Seneca Lake.*

Three miles north of Watkins. Column of figures refers to elevation with reference to sealevel Vertical scale exaggerated about five times.

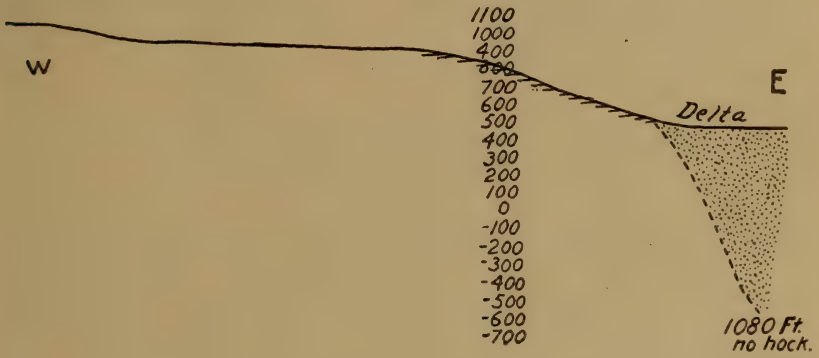

W
1100
1000
400
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
E
Delta
1080 Ft.
no hock.

FIGURE 2.—*Profile along Watkins Glen Creek.*

Scale same as figure 1.

The headwaters of the hanging valleys are far less mature than the lower reaches, for from the headwaters the valleys broaden downstream, while the valley walls become less steep. A gorge condition exists in many of the headwater tributaries, and the valley walls are almost uniformly steep, indicating that active erosion was in progress here when the new cycle was introduced by which the main valley bottoms were lowered.

Hanging valleys in the Tiougnioga trough.—The Tiougnioga valley, which extends southeastward from near Cortland across the Cortland and Harford topographic sheets, carries southward to the Susquehanna the headwaters of the Fall Creek drainage area, normally tributary to Cayuga lake* (see plate 39, figure 1). From near Cortland to a point about 3 miles south of Blodgett Mills the valley narrows, becoming there a deep, steep-sided, gorge-like valley, below which there is again a broadening. This narrow section is without doubt an old divide region across which the upper Fall creek has been diverted.

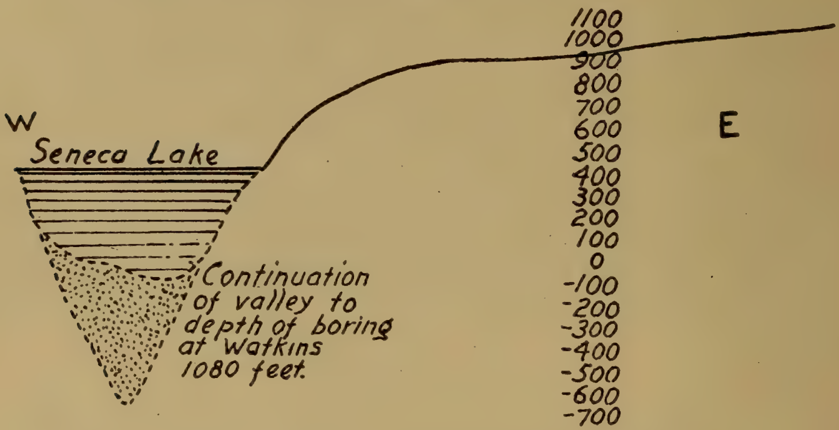


Figure 3.—*Profile of Hector Falls Creek, Seneca Valley.*

Two and one-half miles north of Watkins. Scale same as figure 1.

On either side of this valley, both above and below the narrow gorge, the tributaries occupy gorges cut in hanging valleys. The upper portions of these tributaries are in broad, mature valleys, while the lower portions are in rock-walled gorges 50 to 100 feet in depth, resembling in appearance the buried gorges in the Cayuga and Seneca troughs. In each case the gorge is cut in a rock bench extending across the mouths of hanging valleys. Viewed from the opposite side of the Tiougnioga valley, these tributary valleys are plainly seen to be hanging above the main valley, with the gorges cut in their bottoms.

That these gorges are not post-Glacial is proved by the presence in them of drift deposits and, in at least two cases, of buried sections so completely filled with drift that the present stream has been turned aside and forced to cut a narrower gorge apparently entirely of post-Glacial age. While this condition of hanging valleys is present in a number of the tributaries, it is most typically illustrated in East Virgil creek, west of Messengerville on the Harford sheet, and in an unnamed creek on the east side of the valley about 2 miles south of Blodgett Mills on the Cortland sheet. It is in these two valleys that the buried gorge sections are found.

---

* Carney: Journal of Geography, vol. ii, 1903, pp. 115-124.

Other hanging valleys.—In a number of places on the Watkins Glen quadrangle there are hanging valleys, though in most cases not as typical as those described above. More or less completely drift-filled gorges cut in rock benches across the valley mouths, and changing upstream to broad, mature valleys are common. This condition is illustrated very clearly in a number of the tributaries to Cayuta creek between Van Etten and Waverly. In the work on this folio it has not been possible to carefully investigate each of the suspected hanging valleys, and therefore it can not be stated just how many such valleys there are; but enough have been proved to exist to demonstrate that the hanging valley condition is widespread in this region. Far the most perfect examples are those of the Cayuga and Seneca troughs, but the instances in the Tiougnioga and Cayuta valleys are just as certainly instances of hanging valleys. Extension of these studies to other areas and correlation of the results obtained will, it is hoped, warrant interpretation not now possible.

LOWERED DIVIDES

General conditions.—One of the most striking features in the topography of the divide region between the Saint Lawrence and Susquehanna drainage is the marked absence of well defined divides between the larger streams which head in this region. Along a number of valleys it is possible to pass from one drainage system to the other through open valleys in which the present divides are determined not by rock but by drift deposits. A similar condition is found between the headwaters of the larger tributaries on each side of the main divide; and even in the case of the smaller tributaries there is frequently a condition of lowered divides. In discussing this paper at the Geological Society meeting in Philadelphia Professor Davis applied the very descriptive name of "through valleys" to this condition of valleys connected across lowered divides.

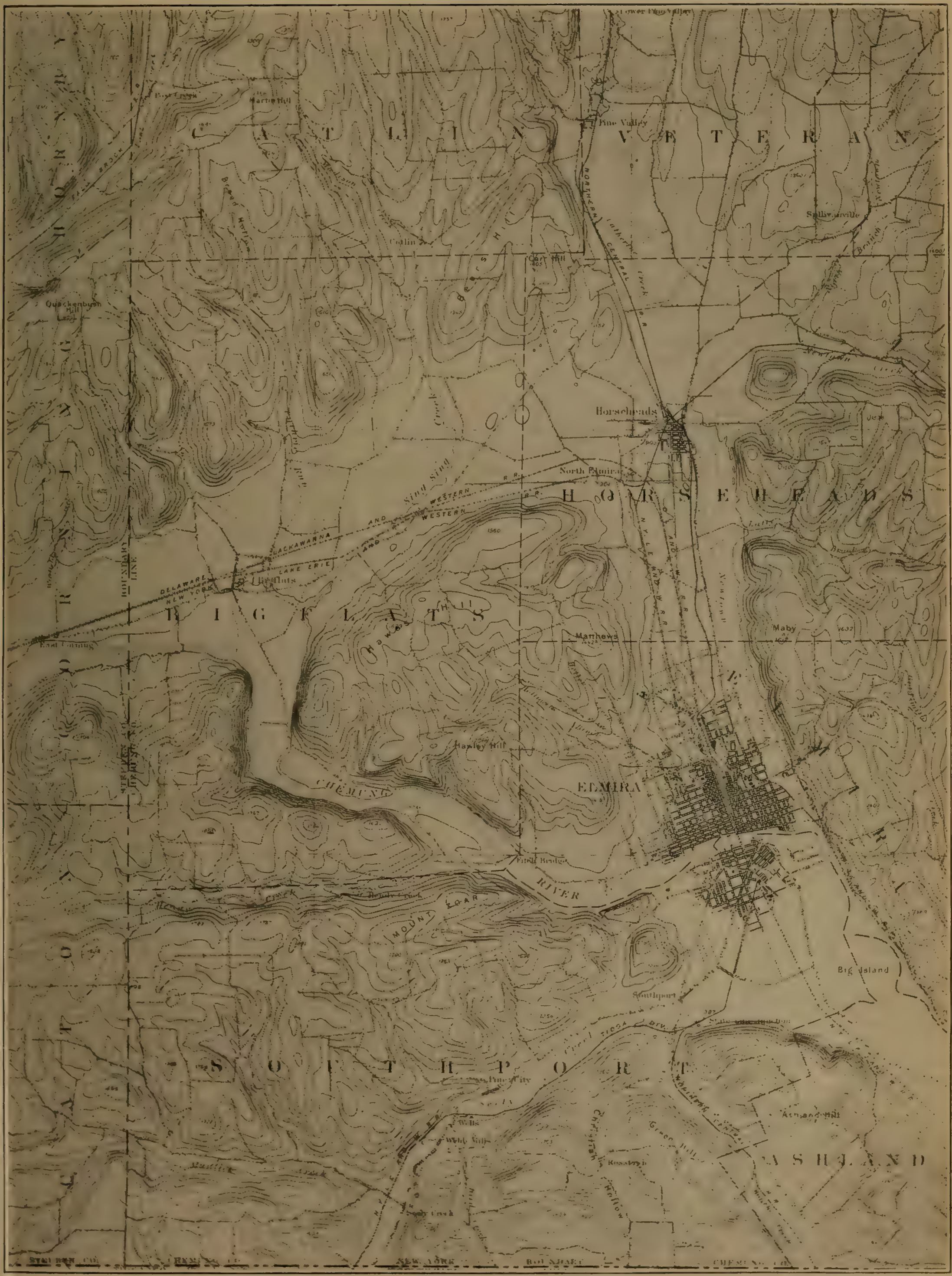
Accompanying this condition there has been much diversion of drainage across the lowered divides, so that it is very frequently the case that the present divide does not coincide with an earlier position. This is proved by the fact that streams frequently head on drift deposits in a broadly open valley, flow toward a narrowing section of the valley, pass through a gorge with rock walls and drift floor, and thence on into another broader section. These conditions may best be understood by describing several specific instances.

Seneca and Cayuga valleys.—In both these valleys (plate 37) there is an open trough southward across the present divide, which is in drift; and in both cases one side, and in some cases both sides of the valley have precipitous sides. A canal and a railway have passed across the Seneca divide with moderate grade, and a railway with a somewhat steeper grade passes through the Cayuga trough. In these two valleys the topography does not demonstrate the exact location of the earlier divide

The Chemung near Elmira.—From Corning to Elmira there is a broad valley swinging northward past Horseheads, and followed by two railroads (see plate 40). The Chemung river leaves this valley near Big Flats and makes a cross-cut to Elmira behind a high mass of hills. This section of the valley is much narrower than the abandoned portion past Horseheads, and it flares both ways from a narrow gorge section, evidently the site of an old divide. No rock is encountered by the stream, and the valley is partly filled and clogged with glacial drift, including well defined moraines.

Near this region there are four smaller hills, with valleys behind them flaring both ways from a central divide, which bear a close resemblance to the valley followed by the Chemung. Two of these lie about 2 miles southwest of Elmira (see plate 41, figure 1), one about 2 miles northeast, and one about 2 miles northwest of Horseheads (see plate 40). If the plain of outwash gravels over which the Chemung flows had been built 100 feet higher, there would be in these cases an almost exact duplication of the conditions in the Chemung valley, only on a smaller scale (see plate 40).

Cayuta valley.—Next to the Chemung river, Cayuta creek is the longest stream on the Watkins Glen quadrangle. It is, however, joined by no large tributaries, and for most of the distance its divide is within from 2 to 4 miles of the creek. Its valley has two narrow, gorge-like sections, in each case with a broadening of the valley in both directions from the narrow portion (see plate 37). One of these narrow sections is about midway between Cayuta and Rodbourn and one between Van Etten and Waverly. The topography clearly indicates that the narrow sections were the sites of earlier divides, and that parts of three stream systems have been united to form a single creek. One portion was tributary to the Seneca valley, one flowed eastward past Spencer, and the third, as now, southward to the Chemung river at Waverly. This valley is fol-


C A T L I N
V E T E R A N
H O R S E H E A D S
B I G F L A T S
S O U T H P O R T
A S H L A N D
C O R N I N G
Lower Pine Valley
Pine Valley
Hartin Hill
Quackenbush Hill
Colin
Sullivanville
Horseheads
North Elmira
Big Flats
East Corning
Mathews
Maby
Hawley Hill
ELMIRA
First Bridge
CHEMUNG RIVER
MOUNT ZOAR
Southport
Big Island
Pine City
Wells
Ashland Hill
DELAWARE LACKAWANNA AND WESTERN R.R.
NEW YORK LAKE ERIE AND WESTERN
NORTHERN CENTRAL R.R.
BOUNDARY LINE
STEUBEN CO.
CHEMUNG CO.
NEW YORK

DIVERSION OF THE CHEMUNG RIVER NEAR ELMIRA, NEW YORK

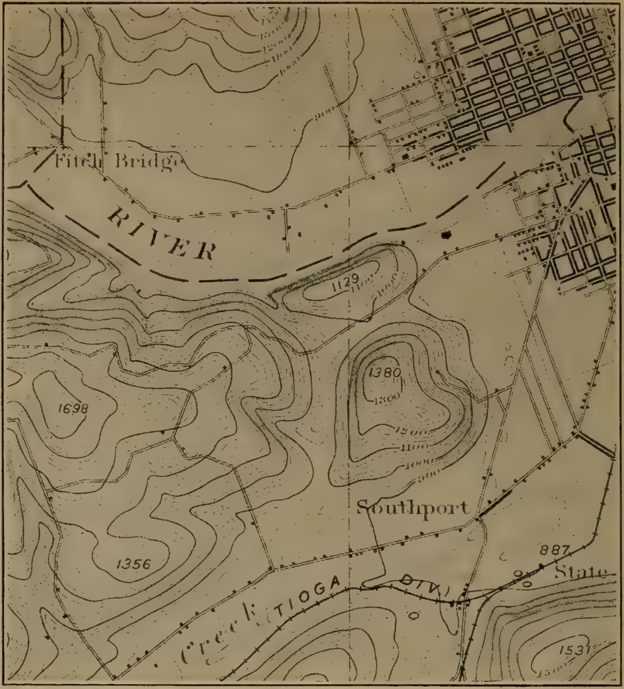

Fitch Bridge
RIVER
1129
1380
1698
1356
Southport
887
State
TIOGA DIV
Creek
1531

Figure 1.—Lowered Divides Southeast of Elmira

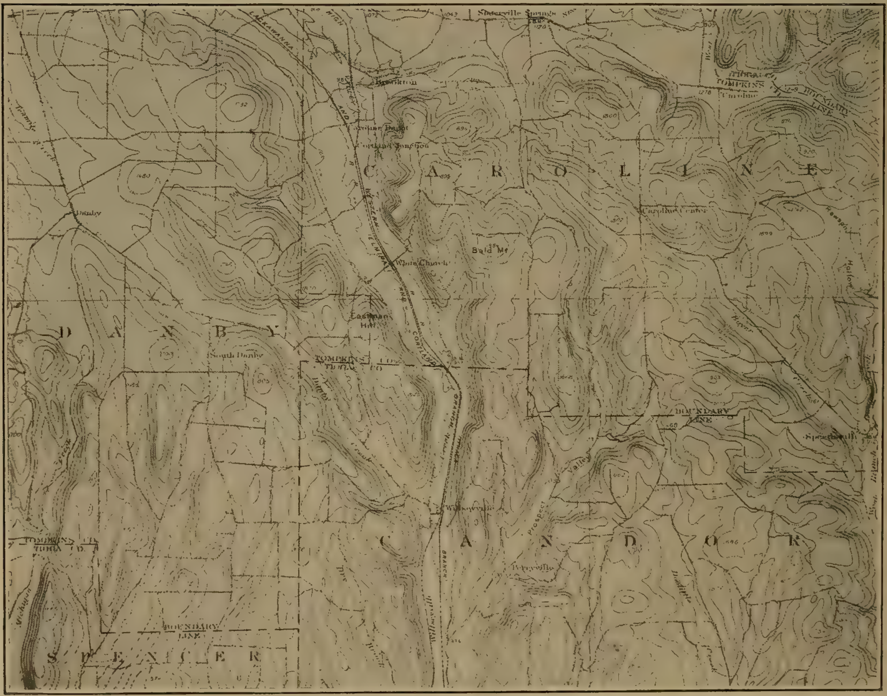

Brookton
CAROLINE
Caroline Center
Bald Mt
White Church
Eastman Hill
DANBY
South Danby
TOMPKINS CO
TIOGA CO
BOUNDARY LINE
CANDOR
Willseyville
SPENCER

Figure 2.—The Willseyville Valley

LOWERED DIVIDES SOUTHWEST OF ELMIRA AND WILLSEYVILLE VALLEY lowed by the main line of the Lehigh Valley railroad, and toward the east, past Van Etten, by a branch of this railroad. The present divides are low drift masses, and any old divides that may have existed have been completely obliterated, so that no rock is encountered in the stream course.

Tiougnioga valley.—Carney* has shown that the headwaters of Fall creek, instead of following the broadening valley toward Ithaca, turn southward at Cortland into a narrowing valley, through a gorge section, evidently the site of an old divide, and thence into a broadening valley. As has been stated above, this doubly flaring valley has tributaries hanging well above the present valley bottom on both sides of the narrow section. Drift fills the valley, till and moraine occur on its sides, and no rock is encountered in its bottom, even in the narrowest part (see plate 39, figure 1).

Willseyville valley.—Between the headwaters of Six Mile and Willseyville creeks, on the Dryden sheet, there is a deep, gorge-like valley, with walls so steep that they are not cleared of forest (see plate 41, figure 2). The valley bottom is occupied by extensive moraine accumulations, and no rock appears in it, nor any well defined divide, the waters at present parting in the moraine. Toward the narrow gorge portion the valley narrows from each side, indicating the location of a former divide. At present two railroads pass with easy grade through this peculiar valley. Tributary valleys, with bottoms below the level of the moraine filling of the main valley, enter it in the narrow gorge portion.

Other instances.—It would be possible to multiply the instances of this condition from the southern central portion of New York. For example, confining attention to the Watkins Glen quadrangle, Post creek, on the western side of the quadrangle southwest of Watkins (see plate 37), flows from a broad into a narrowing valley. There is no definite divide in the Burdett-Reynoldsville valley northeast of Watkins, nor between the upper Taghanic and Cayuta Lake valleys, nor the Pony Hollow and Butternut valleys (see plates 37 and 38). It may be said, in fact, that there is no single case of a well defined rock divide between the headwaters of the main branches of any of the larger streams on the Watkins Glen quadrangle.

Texas hollow.—This valley is one of the most peculiar in the Watkins Glen quadrangle (see plate 42, figure 1). It is a deep valley with sides so steep that for the greater part of the distance the forest remains, and no road ascends to the upland; and it is so narrow at the bottom that, excepting at the ends, there are only a few small, poor farms. The valley broadens both ways from a narrow central portion, in which there is a low rock divide near the present divide, which is in drift. This "hollow" is therefore a double valley, with both a sloping bottom and flaring walls on each side of the divide. Its form is gorge-like, its walls remarkably straight and smooth, and its tributaries confined to small streams, which head on the very edge of the "hollow."

---

* Journal of Geography, vol. ii, 1903, pp. 115-124.

Such steep, smooth, straight valley walls, though nowhere on the Watkins Glen quadrangle as well developed as in Texas hollow, are, nevertheless, a common type of topography in this region (see plates 37 and 38). They are found, for example, south of both Watkins and Ithaca; in the Cayuta valley; near Elmira; in the valley southwest of Mecklenburg; and in many other places. Such valley walls are most perfectly developed in the neighborhood of lowered divides, and they occur in both north-south and east-west valleys.

Divides of smaller streams.—Many of the smaller headwaters are located in broad, cirque-like, upland valleys, whose divide crest commonly reaches elevations of from 1,500 to 1,800 feet. These upland valleys, which are decidedly mature in form, frequently have gorges cut in their bottoms, and in some cases are breached by gorges. The best and most typical instance of this so far observed is on the very edge of the Watkins sheet, almost due west of Watkins. A very perfect cirque-like valley faces eastward, and the smooth, regular divide is cut completely across by the gorge of a west-flowing stream.

From this condition there is every stage to such cases of complete obliteration of divides as those described above. Southwest of Van Etten, for instance, the divide between Baker and Wyncoop creeks (see plate 42, figure 2), is a low, flat-bottomed valley, bounded by smooth, straight-sided, precipitous walls. Just south of Breesport, at the head of Baldwin Creek valley, the divide is so low that if the gravel plain that was built at the closing stages of the ice occupation could be removed Newtown creek could be easily diverted across it. These instances may serve as types which could be added to if it were necessary; and it should be noted that both in the large and small valleys there are instances of lowered divides extending in all directions.

Present stream courses.—The facts stated above prove conclusively that there has been a widespread condition of divide lowering in the region under consideration. Exactly the extent to which this lowering has been carried in the major valleys is not certain because of the drift filling; but in some of the smaller valleys the divide lowering has not gone so far that the glacial deposits have obliterated the rock divide.

Whatever the cause for the lowering of the divides, the present stream

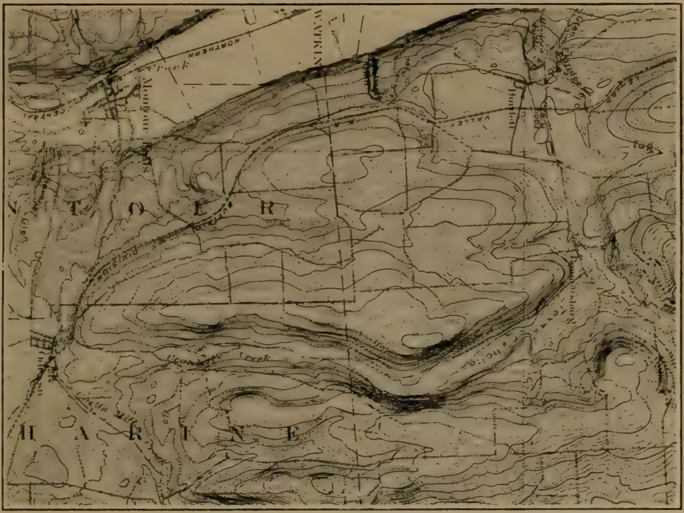

NORTHERN
CENTRAL
WATKINS
VALLEY
Creek

Figure 1.—Texas Hollow Trough

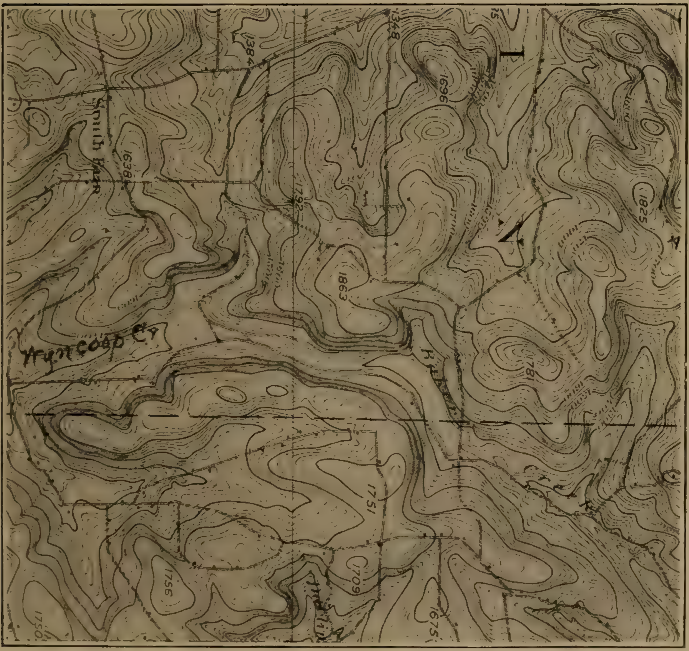

1384
1348
1696
South
1638
1792
1825
1863
Wyncoop Cr
1781
1751
1756
1709
1675
1750

Figure 2.—Divide between Baker and Wyncoop Creeks

TEXAS HOLLOW TROUGH AND DIVIDE BETWEEN BAKER AND WYNCOOP CREEKS

courses, which so often lead across the sites of ancient divides, are due to the fact that glacial deposits have so graded the valleys as to make streams of two systems unite in a single course. For instance, in both Post Creek and Pony Hollow valleys, moraines form the present divides, and outwash gravel plains supply a grade down which the streams flow across ancient divide sites. The same is true of Cayuta creek. The course of the Chemung west of Elmira is also determined by outwash gravels, which spread fan-shaped from the neighborhood of Horseheads, both toward Elmira and Big Flats, making the part of the valley near Horseheads higher than those parts farther away from the moraines, during the building of which the outwash gravels were supplied.

By these morainic and outwash gravel deposits the present divides have to a large degree been determined, and, as a result of the changes thus brought about, the drainage of this divide region has been profoundly altered; but without a previous lowering of the divides these decided changes in drainage would not have been possible.

INTERPRETATION

STATEMENT OF HYPOTHESES

Three different hypotheses suggest themselves as possible explanations of the drainage peculiarities described above: (1) Ice erosion; (2) erosion by ice-born streams; and (3) headwater erosion, lowering divides and capturing opposing headwaters. The ice-erosion hypothesis must include not only the last ice advance, but also earlier ice advances, of which, however, there is no direct evidence so far discovered in this region. The same is true of the hypothesis of ice born streams; and, in addition, the possibility of water erosion during both the advance and retreat of each ice sheet must be considered. These hypotheses will be considered separately.

ICE-EROSION HYPOTHESIS

A number of facts are opposed to this hypothesis. In the first place, as has been stated elsewhere,* there is in this region definite evidence of weak ice erosion during the last ice advance. Residually decayed rock abounds in the southern half of the quadrangle, and some is present even on the margin of Cayuga lake below the edge of the steepened slope. Moreover, gorges cut in the steepened slope have not been erased nor distinctly modified in form by ice erosion. If it is true that the last ice advance in a main valley like the Cayuga trough did not perform marked erosion, it would seem certain that ice erosion in less favorably situated valleys could not have been great. Furthermore, some of the best instances of "through valleys" are south of the zone of most active ice erosion and in a region where residually decayed rock abounds.

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*R. S. Tarr: American Geologist, vol. xxxiii, 1904, p. 286; Journal of Geology, vol. xiii, 1905, p. 160.

The great number of instances of lowered divides and steepened slopes, in valleys of all sizes and extending in all directions, would demand an altogether remarkable irregularity of ice movement. This may be illustrated by the case of the Chemung west of Elmira (see plate 40). To account for its lowered divide, ice would have to move either east or west; but at the end of its narrow section, 2 miles southwest of Elmira, are two small hills with valleys similar to that of the Chemung, one extending north and south, the other east and west (see plate 41, figure 1). These three valleys are apparently of the same origin, for, barring size, their characteristics are essentially the same. To account for them by ice erosion would require ice movement in two valleys at right angles and all within an area of a square mile.

The flaring of the valleys in two directions from a narrow central portion hardly seems a probable result of ice erosion. In Texas hollow, for example, the same characteristics of valley wall form extend both north and south of the narrowest part. It is a question whether, in the case of ice passing through a narrow divide gap, its movement would not be checked by the narrowing valley and a tendency toward stagnant conditions be brought about. Especially would this seem to be the case where the valley extended at an angle to the general ice motion, as was the case in a large number of instances in this region, including Texas hollow.

There are some cases where ice erosion by the Wisconsin ice sheet is entirely out of the question. This is best illustrated in the Tiougnioga valley, where, on each side of the narrow gorge portion, there is a condition of hanging valleys with gorges in their bottoms, which were developed before the Wisconsin ice advanced. In the Willseyville and Cayuta valleys also there are tributary valleys developed after the lowered divide conditions were brought into existence, and therefore, since they are drift filled, before the last ice advance. Since this has been proved to be true of several valleys, it seems probable that it is true also of others, concerning which such definite proof has not yet been found.

Altogether the facts weaken the ice-erosion hypothesis, and in some of the valleys the evidence is definite that their condition is not due to ice erosion during the Wisconsin ice advance. Facts have not been discovered which disprove the hypothesis that these valley conditions are due to an earlier ice advance; and, although no evidence of such earlier ice advances in this region has been discovered so far, that hypothesis must still be held as a working hypothesis in future studies.

ICE-BORN STREAM-EROSION HYPOTHESIS

Wherever positive evidence could be discovered in this area the erosion of streams associated with the melting of the Wisconsin ice sheet was found to be very slight, in most cases amounting merely to a notching of the drift deposits. The ice-born streams were depositing rather than eroding profoundly. That the peculiarities of the valleys described above are not in any important degree due to erosion by streams flowing at the closing stages of the last ice advance is demonstrated by the fact that practically all the valleys contain undisturbed morainic deposits which could not have escaped destruction if there had been marked erosion by ice-born streams.

This form of evidence does not, however, eliminate the possibility of water erosion connected with the advance of the Wisconsin ice; but in certain cases, like the Tiougnioga, Cayuta, and Willseyville valleys, the presence of older buried tributaries does eliminate this hypothesis for these par ticular cases, and, since they are analogous to the others, weakens the hypothesis that they are due to water erosion during the advance of the Wisconsin ice sheet.

The great number of instances, extending in all directions, and of all sizes, would call for a vast amount of water erosion under very variable conditions. I find it exceedingly difficult, for example, to postulate any conceivable set of conditions by which ice-born stream erosion could possibly cut the complex of channels near Elmira and Horseheads, described above. Moreover, it does not seem possible that water erosion of overflow or marginal type could form the doubly flaring condition of Texas Hollow valley, nor the Chemung valley west of Elmira, nor a score of other similar valleys.

Even if several ice advances have been involved, and a large number of ice front positions are postulated to account for these peculiar valleys, the efficiency of glacially supplied streams to form such topographic features is questionable. While the ice was advancing and receding from this hilly region its front could not at any time have long stood *on* the divides, and while it did, judging from the history recorded at the closing stages of the last ice advance, deposition would seem to have been the rule, not erosion. When the ice fronts stood north of the divides there were marginal lake conditions, and the inefficiency of such a river as the Niagara or the Saint Lawrence to form a rock gorge does not lend much support to the hypothesis that the overflows of the glacial lakes were capable of such profound erosion as that necessary to account for the many deep, long cuts in the divide region of southern New York.

From the facts, as indicated in the above outline, it is evident that the peculiar valley conditions of this area are not the result of the action of streams supplied by the melting of the Wisconsin ice sheet, and that in several instances, at least, the conditions were brought about long before the advent of this ice sheet. The hypothesis that these conditions were brought into existence by possible earlier ice advances is weakened by several facts aside from the fact that studies in this region have not yet revealed any evidence of the presence of former ice sheets. It must, nevertheless, remain as a working hypothesis until either some other explanation is established or this one eliminated.

HEADWATER-EROSION HYPOTHESIS

On this hypothesis the assumption is that streams gnawing at their headwaters have in many cases so lowered the divides as to permit complete diversion of streams across these divides when the valleys have been graded up by glacial deposits. By this hypothesis it is further assumed that the gnawing back at the headwaters often caused an encroachment of one stream system on the opposing system and the consequent capture of the headwaters of rival streams in favorable cases. At the present stage of the study it does not seem wise to enter into the consideration of why this headwater erosion may have been in progress nor exactly how it was operating. Further study over a wider area may make this consideration desirable at a later time.

The difficulties in the way of accepting either ice erosion or ice-born stream erosion as an explanation of the peculiar valley conditions of this area may be considered as favorable to the headwater-erosion hypothesis. Moreover, many of the facts opposing the rival hypotheses directly support headwater erosion. The doubly flaring condition of the valleys is a type of form that such headwater erosion would be expected to produce.

If two streams heading in the narrow part of the Chemung valley west of Elmira were lowering their divides, just such a condition as exists west of Elmira would be produced. This process of divide lowering seems to have been in progress behind the small hills 2 miles southwest of Elmira and behind those northeast and northwest of Horseheads. In fact, in many places there are lowered divides in all stages of lowering, from simple notching of the divides to such complete reduction as to permit burial beneath glacial deposits.

That before the glacial period stream erosion was vigorous throughout this divide region is evident from the steep slopes of the valley sides both in the small and the large valleys and from the presence of gorges in many of the valleys. Neither glacial erosion nor ice-born stream erosion, even with the maximum possible number of ice advances, can possibly be appealed to in explanation of all these steep valley slopes, and since they harmonize in form with the steep slopes of the lowered divides they lend support to the hypothesis of headwater erosion for the lowered divides.

On the other hand, as has been suggested to the author by both Doctor Gilbert and Professor Davis, such a condition of "through valleys," while not uncommon in regions of faulting or in regions of inclined and varied strata, has not been described in regions of horizontal strata outside the glacial belt. I have examined several hundred sheets of the United States Geological Survey topographic map in regions outside the glaciated area without finding even an approach to the conditions described above. To this difficulty must be added that of understanding just how divide lowering, operating excessively in some valleys, has produced no effect whatsoever in neighboring headwaters.

DISCORDANCE OF THE CAYUGA AND SENECA VALLEYS

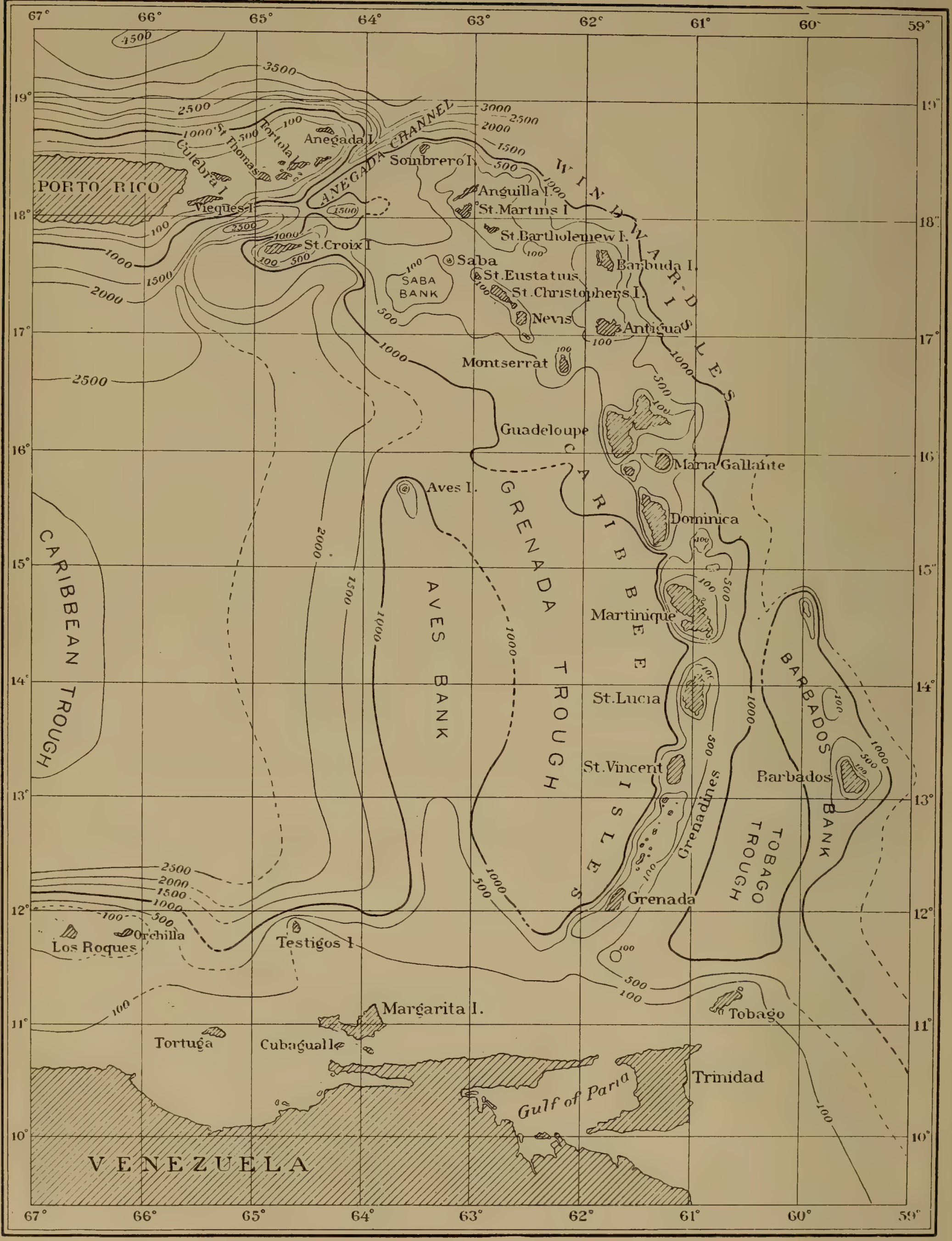
The lowering of the divides is in no way related to rejuvenation resulting from the deepening of the Cayuga and Seneca valleys, for it extends outside of their drainage areas, and, even where developed in the headwaters of tributaries to these two valleys, occurs in valleys hanging high above the bottom of the main lake troughs. The upper parts of these hanging valleys are broad, deep, and steep-sided, with the main divides obliterated by erosion and glacial deposit, but with the lower ends terminating on the edge of a steepened slope notched only by small gorges. This fact favors the theory of glacial erosion for the basins of these two lakes, although other facts, stated in another paper, oppose it.

Conclusions

The one conclusive result of the studies so far made toward the solution of this drainage problem is that, in several typical instances, the phenomenon of lowered divides antedates the last or Wisconsin ice invasion. The establishment of this fact is the excuse for the present paper.

In all other respects this paper must stand as an unfinished study, in which certain observations are recorded and difficulties opposing each of three hypotheses pointed out.

The complete solution of the problem has not yet been reached, but some progress has been made; and, since others as well as the writer are at work on this complex field, this report of progress is made in the hope that it may serve as a slight contribution toward the ultimate unraveling of the events which have caused the peculiarities of drainage in this region.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St. Thomas
Tortola
Anegada I.
ANEGADA CHANNEL
Sombrero I.
Vieques I.
St. Croix I.
Anguilla I.
St. Martins I.
St. Bartholemew I.
Saba
SABA BANK
St. Eustatius
St. Christophers I.
Nevis
Barbuda I.
Antigua
Montserrat
WINDWARD ISLES
Guadeloupe
Maria Gallante
Aves I.
Dominica
CARIBBEAN TROUGH
AVES BANK
GRENADA TROUGH
CARIBBEE ISLES
Martinique
St. Lucia
St. Vincent
Grenadines
Barbados
BARBADOS BANK
TOBAGO TROUGH
Grenada
Los Roques
Orchilla
Testigos I.
Margarita I.
Tobago
Tortuga
Cubagua I.
Trinidad
Gulf of Paria
VENEZUELA

SUBMARINE CONFIGURATION OF THE WINDWARD ARCHIPELAGO

Figures are in fathoms. Dotted lines, owing to lack of soundings, are conjectural. Compiled for Professor Alexander Agassiz from all known data by Robert T. Hill.

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PELÉ AND THE EVOLUTION OF THE WINDWARD ARCHIPELAGO

BY ROBERT T. HILL

(Presented before the Society December 31, 1904)

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INTRODUCTION

VOLCANIC ERUPTIONS OF 1902 AND HOW THEY WERE STUDIED

Three years have passed since the cataclysm of mont Pelé recalled to the world the existence of the Caribbean islands and their volcanoes. At first there was an urgent demand for news concerning the incident, and interest concentrated more in the human than in the scientific side of the story. Corps of photographers, reporters, journalists, geologists, and geographers were hurried to the islands by enterprising publications, societies, and individuals. Publishers required immediate copy, and although the scientific writers demurred to hasty delivery, because there had not been sufficient time for study and deduction of data, the remuneration offered was such that narratives had to be forthcoming. This ravenous public desire for information was as ephemeral as the great tragedy itself, for when, nearly three months later, Martinique suffered another terrible holocaust the incident received but a few lines of mention.

Among the geologists of the *Dixie* expedition were Professors Jaggar, of Harvard; Hovey, of the New York Museum of Natural History; Professor Russell, and the writer, representing the National Geographic Society. Professor Angelo Heilprin, of the Philadelphia Academy of Science, also arrived a little later. The Royal Society of England sent out an excellent commission, composed of Messrs Flett and Anderson. Shortly afterward a commission of French geologists, headed by Professor Lacroix, pursued continuous investigations on the ground. Still later Professor Karl Sapper, the German savant, added the value of his personal observations to the event. Professors Hovey and Jaggar remained on the island after many of us left and obtained additional detailed data concerning the volcanoes. Professor Heilprin made a second visit to Pelé in August and Professor Hovey returned to the island in February, 1903.

The observations of all the earlier parties were fragmentary, and the acquisition of knowledge of the volcanoes has been gradual and progressive. With the possible exception of the French commission, the studies of the geologists were largely devoted to the examination of the immediate geologic phenomena of the volcano. The American observers, notwithstanding the excellent results, were not provided with funds for extended observation or equipped to study the great physical and chemical problems of the Martinique eruption.* The French commission alone seems to have located on the island with a view to continuous study. Observations of these parties appear from time to time in various places, each containing some valuable contribution, the aggregate of which is our present knowledge.

LITERATURE

The literature † of the Pelé eruption recording the observations of these many observers is extensive and excellent, although volumes could still be written on the unpublished technical details and human tragedies. This literature, however, notwithstanding its value, is largely a story of uncorrelated detail and only records the accompanying incidents of a larger and more wondrous story which is the object of this paper to present.

SCOPE OF THE LARGER STORY OF PELÉ

This larger story is that of the history and work of the Caribbean volcanoes as a whole, of which Pelé is but a part, and the light which it throws on the fundamental nature and causes of vulcanism. It is a story of the world at work, as illustrated in the geologic and present history of one of its areas. It is the record of the geologic evolution of the Windward archipelago.

In this larger story Pelé is not treated as an accident of a day or a year, but as a persistent permanent volcanic mechanism, whose action has extended far back through the incomprehensible perspective of time which we call geological; nor is its work measured by the destruction of a few acres of vegetation and human life, but the construction of things larger—islands, oceans, continents, and perhaps even the world itself.

In order to attempt to tell this larger story we must take up the difficult task of relegating the vast phenomenon of the recent eruptions to its proper position as one of hundreds of similar incidents which have taken place at the site of this venerable historic chimney, and of condensing into general comprehensible language the volume of technical details on which this larger story is founded.

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* The writer and others vainly endeavored to interest institutions with large funds for research in providing for a wider and more systematic study of Pelé by Americans.

† A good bibliography of the literature by Professor I. C. Russell will be found in the Smithsonian Report for 1903; also by E. O. Hovey and others in various papers. Mr Hovey's excellent bibliography was printed in the Bulletin of the Geological Society of America, vol 15, pp. 562-566, under the title "Bibliography of literature of the West Indian eruptions published in the United States."

THE VOLCANO PELÉ

SUMMARY OF THE RECENT ERUPTION NECESSARY

It is important to have a correct appreciation of the mechanism and the events of the recent eruption in order to understand exactly similar incidents which have been taking place through indefinite times past. Inasmuch as the statements of the somewhat hastily published accounts (in which there were also some discrepancies) have not been sifted and summarized, it will be necessary first to present a brief résumé of what actually occurred in nature during the recent period of eruptions.

MECHANISM AND WORK OF THE VOLCANO

The mechanism of Pelé (and of volcanoes in general) is comparable to that of a mighty blast furnace with high internal temperatures. The object to be accomplished in the man-made blast furnace is to decompose elements or compounds into gases by the aid of high temperatures, which make new combinations on cooling. In the volcanic furnaces, with the increase or decrease of heat, there is an infinite series of changes in physical form (gaseous, solid, or liquid) and chemical recombination of the matter, finally resulting in the production of the familiar volcanic substances which we see at or near its exits as vapors and slags.

But the volcanoes which we actually see at the surface, with all their majestic phenomena, are merely the chimneys protruding at the surface above the larger actual furnace, which is deeply concealed within the earth's interior.

These visible parts are relatively secondary. They consist of (1) the outer end of a conduit of some kind extending to the surface from the interior furnace of the earth, surrounded by (2) an ash pile or constructional volcanic mountain (like mont Pelé) of long accumulation, composed of a minute portion of the debris or by-products which have ascended through the vent hole and which have been deposited around its orifice.

Reduced to its simplest statement, the visible feature of the mechanism of the Pelé volcano was the self-constructed terminal vent of the volcanic chimney or conduit through which escaped the ash and gaseous products of the real and essential mechanism concealed within the earth.*

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* While the conduit of which the actual volcano was but the terminal vent which clogs up after each period of eruption, which may be considered a passage or crevice leading up from the subcrustal portion of the earth to the surface, it is not necessarily a definite open tube or pipe, but rather a locus of extrusion above the potentially permanent deeper mechanism.

The cone or summit (somma) crowning the old ash pile of Pelé prior to the present series of eruptions was not exactly funnel shaped, but practically a deep, flat bowl (caldera) within the approximate top of the mountain, the rim of which was somewhat irregular, with walls rising from 16 to 21 feet above the level of its bottom. The highest peak of the old mountain, approximately 4,300 feet, represented a portion of the rim of the summit bowl. The particular feature of this crater bowl of human interest was the great gash or break in its western side leading out to the rivers which flow toward the northern suburbs of Saint Pierre. This gash, known as La Fente, played an important part in the minor natural incident, the destruction of Saint Pierre. It must be admitted, however, that the chief feature of the surface mechanism of Pelé was a summit cone, and the present paper does not concern the details of its minor accompanying phenomena, which have been so fully presented by Professor Hovey and foreign geologists.

There is a popular misconception that volcanoes are engines of destruction, and hence in the earlier days of excitement immediately following the extermination of Saint Pierre there were many rumors and prophecies of geologic disaster. Dispatches asserted the lowering of the mountain tops and the sinking of the bottoms of the Caribbean sea. It was announced that great fissures had opened in the ocean and the dome of the island had been blown away. The instability of the earth's crust in the vicinity was dwelt on and the early destruction of the island by explosion and tidal waves was predicted.

The awe-inspiring aspects of this work which attracted human interest, when considered separately and from the human view-point, were locally destructive, but the destruction, as we shall show, was but trivial in comparison to the great constructive work of building up accomplished by the general incident.

The apparent work was the expulsion of clouds of steam and ashes, accompanied by showers of stone and debris dislodged from the old crater walls or floor, the discharge of streams of hot boulders and hot mud down the valley of the radiating rivers leading toward Saint Pierre, the deposition of quantities of lapilli over the surface of the surrounding area, and the later protrusion of the wonderful spine.

But before any of these things happened the volcano was at work within, and this first phase of the work, and that which is least understood, was the great chemical reorganization of the matter beneath the surface. The molten magma, rocks, lapilli, and all other material seen at the surface were but secondary products of larger primary work within the earth by which the elements there existing in some entirely different state were transformed and recombined into the materials as we now see them. The original source and nature of this matter before it acquired the form and composition with which it made its exit, involving the ultimate cause of vulcanism, is the great secret of the earth's interior and largely a matter of scientific speculation, which will be more fully discussed in the final pages of this paper. The chemical and physical changes of this primitive matter in its progress from the earth's interior to the surface was the main work of the volcano.

The matter as it reached the surface and atmosphere not only represented the secondary products of the great interior work, but its expulsion at the surface was only one of the many stages of the volcano which was at work long before surface eruptions and which will continue at work long after they have ceased. These stages of the apparent work are:

1. The quiescent or fumarolic stage representing the normal condition of the volcano in its periods of surface inactivity.
2. The preparatory stage marked by increased fumarolic conditions, slight local earthquakes, increasing temperature of the water, and other conditions indicative of the ascent of the gases and magma in the vicinity of the old conduits.
3. The explosive or catastrophal stage marking the outbreak of the magma at the surface and the clearing the debris which had previously clogged the ancient vents.
4. The active free working stage marked by a continuous series of eruptions from the somma or summit crater.
5. The decadence of force and closing of the vent again.

The first or quiescent stage of the work of the Pelé volcano is well known. The ancient somma was probably filled with water, constituting a lake. Around the sides of the mountain at various places, notably at Precheur, were a few warm springs indicative of the latent temperature beneath the surface.

There is abundant evidence that for months prior to the actual discharge of steam and lapilli the second stage was marked by the gradual ascent of the magma, indicated and announced by increasing temperature of the waters of the lake in the old orifice, increased fumarolic action, slight local tremors and noises within the mountain, swelling of the streams, associated with mud and heat, and the final appearance of clouds of steam and lapilli.*

The third or catastrophal stage of the work of the volcano was specially marked by the destruction of the Usine Guerin on May 5 and the great eruption of May 8, when the ascending column of magma reached the outer atmosphere and discharged from the vents the old material which previously had clogged them.

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*Professor Milne in Nature for November 27, 1902, notes that in Saint Vincent local earthquakes had been on the increase for a year, and as far back as May, 1901, people were frightened away from the northeast end of the Soufriere by rumblings and quakings, but there is no definite record that Martinique was subject to any marked or unusual tremors preceding the first eruption, except in the instances as noted by Mrs Prentice a few days before the catastrophe.

Since then the work has been relatively that of a free conduit, through which incalculable quantities of the earth's interior were transferred to its outer crust. This fourth or free stage was fully attained as early as the eruption of May 26, when sheets or flows of incandescent lapilli began to well over the summit rim. This continued freely for over a year, and was still continuing when Pelé was last heard from.

The material erupted was projected upward by expansive force and distributed by air currents and gravity, the lighter and larger portions ascending into the atmosphere as clouds of steam and ash and floating away to fall over the wide expanse of the adjacent oceans. A fraction of this material, not rising to heights, fell around the vent to add elevation to the rims of its caldera. Some of the largest and more tenaceous material flowed or rolled down the deep canyons of La Fente and into the Rivieres Seche and Blanche.

Although Professor La Croix,* conductor of the French scientific expedition sent to Martinique, has reported an account of how blocks of the incandescent magma rolled in the direction of the Riviere Blanche and filled it, all evidence tends to show that the liquid magma mostly changed into a fragmental condition on reaching the atmosphere and did not flow on the surface as a molten rock—that is, as lava.

During this free working stage the eruptions were marked also by the welling over from the summit crater rim of vast quantities of incandescent particles of ash, which, at the moment of their ejection, resembled fountains of fire, and, as they rolled down the upper slopes of the mountain, were taken for molten lava. This was observed in the eruption of May 26 by the writer and by Messrs Henry, Morse, Smith, and others.

The eruption of July 9, observed by the Royal Society Commission (Flett and Anderson), was typical of the free working stage. It was described as follows:

> "First, spasmodic burst of steam and dust and stones accompanied by discharges of torrents of water and mud; secondly, the welling up in the crater of an overflow like that of a liquid fountain of red-hot dust, which descended the mountain slope at first relatively slowly, but with ever increasing velocity, like an avalanche of snow. . . . As soon as the throat of the crater is reached a mass of incandescent lava rises and rolls over the top of the crater in the forms of red-hot dust. It is a lava blown to pieces by the expansion of the gases it contains. . . . This avalanche of incandescent sand was accompanied by a dense cloud, black as night, which soon concealed it from view and swelled in convolutions with terrible energy

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*See Nature, December, 1902.

until it reached, perhaps, 1 mile high and 2 broad. After this it ceased to enlarge and gradually lost its dense blackness through ash settling down and leaving nothing but white steam."

The final stage of the work of the volcano has probably been reached recently. It was just the reverse of the foregoing events. The force of the ascending magma decreased, the eruptions gradually diminished in intensity and frequency, the vents became clogged by cooling lava, and gradually the orifice closed, although the smouldering magma may continue to push dikes here and there into the foundations of the self-made ash pile.

Until some future period, when another cycle of explosive eruptions will reopen it, Pelé, with its lid again on, will be considered an extinct volcano, and humanity may again inhabit the outer slopes of its chimney. But the real volcano within, banked up with its own debris, is potentially as active as it has always been as far back in time as the human mind can reach.*

PRODUCTS OF THE ERUPTIONS

Rock products.—The visible ejecta from the vent of Pelé have been fragments of rock material, mostly in a finely divided condition, water, and gases of a nature not fully interpreted, which are further discussed in this paper.

The rock products of the volcano were the debris of an ascending, cooling liquid molten magma. This, exploding into fragments as it approached the vent, manifested itself in the forms, mostly of lapilli, sometimes called ash and sometimes sand; boulders of pumice, pseudo bombs, mud, and sometimes the debris of the old conduits. The various forms of rock material were all composed of the mineralogical mixture known as hypersthene-hornblende-andesite, embracing combinations of many elements.†

Water products.—The large quantity of water accompanying the earlier eruptions of Pelé and great clouds of watery vapors were noticeable features. These water products of Pelé were manifest in several ways during the various stages of eruption. During the preparatory stage for several days before the fatal catastrophe the streams descending from Pelé toward Saint Pierre were swollen to thirty times the volume ever known from freshets, and, for a time after the catastrophe, flowed volumes of hot mud. Later, in the free working stage of the volcano, tremendous clouds of steam discharged from the summit and dissipated into the atmosphere. Messrs Flett and Anderson, of the British Commission, have clearly shown that the steam or water was largely contained within particles of lapilli themselves, which emitted vapors on rolling down the crater slopes.

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* The writer and other earlier reporters on the scene submitted evidence that the volcano in its second or catastrophal stage had more than one vent, notably one to the west of the crater in the gorge of the Riviere Blanche and the other to the east of the gorge of La Felisse, as noted by Kennan and Heilprin.

Concerning the existence of the western lateral vent, it was clearly stated, however (Century Magazine, September, 1902, page 775), that "much is desirable to be known about this canyon, its vent, and the condition of its bottom."

The writer was perhaps erroneous in calling this supposed vent of the Riviere Blanche a crater, for its existence was founded on testimony which can now neither be proved nor disproved, and the question of its existence or non-existence is but a minor detail in the larger story we are trying to tell.

†Andesite is a technical term for a volcanic rock intermediate between those which are basic or containing less than 50 per cent of silica and those which are extremely siliceous. In general, they consist approximately of 62 per cent of silica (SiO_2).

Gas products.—From the first the writer maintained that one of the most essential scientific questions presented by the West Indian eruption was the quantity and character of the gases which accompanied them and the light they threw on the nature and history of vulcanism in general. As will be seen in the last chapter of this paper, the question of gases is still the most important one in the whole subject of vulcanism.*

Most of the gases of vulcanism are combined into solid material before reaching the exit. The remainder are difficult to study, as they escape from an active and dangerous volcano. Those gases which remain free sufficiently long to be determined, uncombined with other substances, are merely the expiring after products. Some of these may be readily detected by the senses, others by collecting them from fumaroles; still others are detected only by the products of sublimation ultimately found in the rocks and crevices of the volcano after it has become sufficiently cool for study. It is also probable that many other gases escape which are not discernible by any known method.

Only the evidence concerning these expiring gases in the surface eruptions can now be presented, reserving the discussion of their larger occurrence within for the final chapter. Dana has said that "the chief vapor or gas coming from volcanic lavas is sulphurous acid (SO_2), and with it may be hydrogen and nitrogen." This statement may not be literally accurate, for it is probable that hydrogen and oxygen far excel all other gases in quantity, but sulphurous acid (SO_2), having the smell of sulphur, is among the most apparent and detectable of the vapors. It is always present. The volcanic vents of the Caribbee islands all yield sulphurous vapors. Some of them, as in Dominica and Saint Lucia, deposit the sulphur in considerable quantities. The very name of these quiescent craters, which are called "soufrieres," attests the sulphurous nature of their gases. Hovey and others recognized SO_2 and H_2S in steam of eruptions from Pelé.*

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*According to Geikie the gases of the following elements have been found in volcanic emanations: oxygen, hydrogen, sulphur, chlorine, nitrogen, carbon, fluorine, and iodine. From the subimates and combinations of gases, potassium, iron, copper, lead, borax, and sodium have also been found.

No direct proof of the existence of free hydrogen and oxygen from the craters has been produced nor have spectroscopic studies been made for this purpose. On the other hand, there is every evidence that these materials did emanate from the crater, in combination with each other as water, in tremendous quantities, as elsewhere discussed.

The rumors of carbon gases, which have been frequently found elsewhere in expiring volcanic emanations, have been many. The writer presents the singular story that Professor Landes, the French savant, who lost his life in the eruption, was said to have reported after the destruction of Usine Guerin, on May 5. As related to me by Vice-Mayor Labat, whom I met in Saint Lucia on May 23 and who returned to Fort de France with me on the *Potomac* May 24, it is as follows: After the explosion of May 3, when the mud first ran down the Riviere Blanche, analyses were made by Professor Landes, of the Lycee of Saint Pierre, from day to day. On May 7 Professor Landes sent the following telegram to the governor at Fort de France: "Carburetted hydrogen gas in ashes; dangerous; explain tomorrow." On the morrow he was dead.

Professor Heilprin, in McClure's Magazine for August,† 1902, advanced the hypothesis that there were carbon dioxide gases, derived by ascent of the magma through asphaltic and calcareous strata, constituting the substructure of the island. Later, however, in his book, he withdrew this opinion and attributed the deaths to steam and hot lapilli. While carbon gas was most probably emitted, as later shown by Professor Moissan, the above explanation of its origin is erroneous, for no known calcareous and asphaltic rocks exist in the foundation of Pelé, and there is every geological reason for believing that such rocks do not exist, as set forth herein later.

The undoubted presence of carbon gases, however, has been accurately and scientifically determined and recorded by M. Henri Moissan in a paper before the Academy of Sciences, Paris, December 15 entitled, "On the presence of argon, oxide of carbon, and hydrocarbon in the gas from the fumaroles of mont Pelé, at Martinique." The gas, which was collected by M. Lacroix, emerged at a temperature of about 400 degrees C.‡

> "Besides those gases which have been already mentioned as present in other volcanic eruptions, a considerable quantity of combustible gas was found, together with about 0.7 per cent of argon. The percentage of carbon monoxide (1.6 per cent) would render the gas very toxic, and it is possible that many of the deaths during the eruption may have been due to this cause."

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* American Journal of Science, November, 1902, p. 349.

† Mont Pelé and the tragedy of Martinique.

‡ Nature, London, December 25, 1902, p. 192.

The discovery of argon in the gases of Pelé is interesting.

Hydrochloric acid is one of the gases often found in volcanic emissions, and it is frequently inferred that it signifies that sea water has gained admission, but I doubt this conclusion, as chlorine may be a constituent of the earth's interior. At Vesuvius chlorine is given out which becomes hydrochloric acid as it leaves the liquid lava. Chlorine or hydrochloric gases have as yet not been recorded from Pelé.

Professor Lacroix * and his colleagues have also made observations on the temperature of the expiring gases.† They speak of many fumaroles on the slopes of mont Pelé which emitted gases hot enough to melt lead, though not copper wire.

In a paper on the volcanic conditions in Martinique, Paris Academy of Sciences, April 6, 1903, Professor Lacroix stated that the fiery clouds produced in the eruption of mont Pelé have been observed by him. They consist of large volumes of hot gases and vapors carrying great quantities of fragmentary products, and are the principal agents of destruction. Finally, it is encouraging to know that the able French commission under the leadership of Professor M. A. Lacroix is continuing its researches in the gases of Pelé.

Other features of the volcano, some of which excited the greatest current interest, were the lightning, the earthquakes, and the magnetic storms.

The terrifying lightning accompanying the eruption has been explained away as a secondary phenomenon, the product of the friction resulting from the ascension of currents of hot steam. This explanation may not be entirely true, but the subject is immaterial to our story

The earthquake tremors were local, not general (earth wide), in their effects and most probably due to the vibrations caused by the explosive work we have described.

No satisfactory explanation has been offered concerning the cause of the great magnetic storm which occurred simultaneously with the eruption, but it is a singular coincident, suggestive of conditions pre-

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* The Geographical Journal, March, 1903.

† The intense temperature within the depths of the volcano can be but faintly conceived by any observations of the materials which cooled upon reaching the atmosphere. This gave off its heat slowly. The ash layers of Saint Pierre were still as hot as the hand could bear several miles from the crater twenty-two days after the eruption only a few inches below the surface. Six kilometers from the crater this material, eight days after the eruption, had a temperature exceeding 100 degrees, according to Lacroix. Lacroix has also stated that the temperature of the ash clouds of an eruption 6 miles from the crater was over 150 and under 250 degrees centigrade The temperature within the orifice was certainly sufficient to melt hypersthene-hornblende-andesite, and in the depths it was probably sufficient to convert all or nearly all the materials of the earth's interior into gases or a condition to become gases on release of pressure.

vailing within the interior of the volcano-encrusted earth like those of the sun.

PELÉ'S CONTRIBUTION TO THE EARTH'S SURFACE

The real work of Pelé and volcanic work in general was the transfer of enormous quantities of material from the great unknown reservoir of the earth's interior to its outer crust, depositing layers of ashes over the adjacent ocean, contributing gases and water to the atmosphere, and adding greater height and mass to the preexisting land surface. Hence from a world-making standpoint it was not destructive, but constructive in its effects. Nothing was taken away from the surface of the earth, nothing except life destroyed. Instead there is added numberless tons of matter to that part of the earth alone known to man—its crust. Theoretically, this is the process by which the skin of our supposedly cooling globe has been and is still being formed. In fact, all the known rocks of the earth's crust may be traced back ultimately to igneous origin. It is also the process by which islands have been built up above the ocean's floor, the rocks of which, worn, dissolved, and redistributed in turn, have become sediments of the ocean and the soils of the land.

It would be interesting to be able to compute the actual work thus accomplished by Pelé's recent eruption by estimating the quantity of rock, water, and gases which it actually transferred from the earth's interior to its outer surface. Unfortunately, no record has been made of the number of eruptions during the two years of activity, and hence we can only convey an idea of the enormous total by an analysis.

Professor I. C. Russell has estimated that each one of the clouds from Pelé discharged 40,000,000 cubic feet of solid matter, and that these discharges taking place every five minutes were equivalent to 1,520,000,000 cubic feet per day. Heilprin states that this quantity is one and one-half times that of the sediment which is discharged by the Mississippi river in the course of a whole year, which is 812,500,000,000 pounds, or a mass one square mile in area and 241 feet deep.

Enormous as may appear the quantity of solid matter of each one of these great volcanic clouds which have been projected into the atmosphere almost daily for over two years, it was but an insignificant fraction of the total substance emitted for a greater quantity of material in the shape of vapors and invisible gases passed out with each outbursting cloud of ashes.

It is impossible to estimate the vast volume of gases and water thus contributed. Geologists like Dana and Geikie have estimated the proportions of vapors and gases to solids to be in the ratio of 999 parts of the former to one of the latter.

The thickness of ashes which fell upon the island, partially burying the ruins of the city of Saint Pierre and which added to the height of the mountain, conveys no adequate idea of the quantity of matter ejected. It is safe to believe that only a small per cent of all the solid debris thus discharged immediately fell around the crater to add to the previous mass of the island. Proportionately the quantity of ashes blown into the air from each discharge of the volcano which would fall back on the slopes of the mountain would be comparable to that which would fall back on the platform of a great gun like that at Sandy Hook, should it be loaded with similar ashes, pointed vertically and discharged a mile upward into the air. The remainder distributed into the atmosphere, as ashes, fell over the sea for hundreds of miles, finally settling even on its deepest floors.

It is no idle fancy that the total work of the recent eruption of Pelé, including the solids now preserved on the island, those which have been carried away by wave and wind, and the gases and vapors contributed to the atmosphere and oceans, has equaled a mass of material transferred from the earth's interior to its exterior from this one small vent probably as large in bulk as the whole island of Martinique itself.

Such were the phenomena most conspicuous to the eye of one only of the periods of eruption of Pelé. As gigantic as they were in their manifestations—the new layers of ash added to the soil, the increased height added to the mountain, and the marvelous plug or spine—they give but a feeble idea of the total accomplishment of this underground mechanism of Pelé, for it had been thus working near its present sight at intervals for countless ages. To convey some idea of what this work has been constitutes an important chapter in the larger story of Pelé.

The larger Story

CHARACTER AND ANTIQUITY OF PELE

The volcano Pelé is an old feature, which, measured in human time, has existed for an inestimable period. From the arrival of Columbus its features had but little modification until the recent outbreak. Twice only in the intervening 400 years have its conduits opened to add new layers of ash to the older pile. The recent eruption of Pelé is merely the hereditary successor of a long line of prehistoric eruptions which have intermittently occurred at this same approximate locality for thousands of years.

In fact, the mass of the present island has been built almost entirely from the ashes of similar spasmodic eruptions, separated by long intervals of time, as can be seen from the arrangement of the layers deposited by various eruptions in times past. The age of the volcano is also attested by the excessive erosion of the slopes of the volcanic pile and the truncation of its sea borders. Thus, even though historic evidence were wanting, it is apparent that this volcanic chimney of Pelé is very old, and that it, as well as the whole island of Martinique, is merely the surface ash pile around the chimney or vents of an interior volcanic center, which is a permanent feature, regardless of surface changes.

The summit pile was built up considerably by the recent eruption. These new ash layers were built in turn on the top of a still older one. The whole mountain and island in fact, partly terrestrial and partially submerged (its gradient extending beneath the waters far beyond the present margins of the island), were thus constructed around vents which originally opened at sea bottom, 2 miles beneath the altitude of the present higher summits.

The orifice or chimney of this plutonic mechanism, as is usual with the termination of volcanic conduits, has shifted locally for short distances in the course of its history, but its location has so persisted, within a circumscribed radius above the deeper seated permanent furnace, that it may practically be considered a fixture, although the limits of its field of outbreak in times past have been coincident with the area of the present island of Martinique.

The entire island, as well as its submerged planed off Windward bench, thus covers an area where volcanic orifices have persistently, though intermittently, opened above one continual deep-seated volcanic center, the vents of which clogged up at the surface after each eruption, but broke out again at some slightly different but nearby place at the next eruption.

Thus it has happened in times past that the mornes of Martinique, notably those of Pelé, the Pitons du Carbet, and many others now worn down, have recorded at several outlets the eruptions above a common interior source. Therefore Pelé protrudes above a persistent interior volcanic mechanism which has existed beneath the island of Martinique farther back in human time than we are able to conceive, and in geological time at least to the Cretaceous period.

In other words, Pelé and the whole island of Martinique, to use a medical figure, is a subcutaneous trouble beneath the skin of the earth, which tends to break out occasionally at the surface within an area of circumscribed limitations. The present crater of Pelé represents the acute manifestation and the rest of the island the scar of former activity.

PELÉ A TYPE OF THE VOLCANIC BATTERY OF THE WINDWARD ARCHIPELAGO

But this greater, deeply concealed interior mechanism of Pelé, whose ash piles around its vent holes constitute the mass of the island, is in turn but one of a group of similar mechanisms or the part of a still larger mechanism beneath the numerous active, quiescent, and extinct volcanoes, constituting all the Caribbean islands, and from all of which the interior magma has tended to break forth repeatedly and in a similar manner.

In fact, these islands as a group constitute a vast battery of volcanoes—living and extinct—which from time to time and through countless ages have been the outward manifestations of the interior activities of our supposedly dead but wonderfully living world.

That the vents are all but chimneys from a common source of supply was certainly indicated by the recent synchronism of the Martinique and Saint Vincent eruptions.*

HOW THE LARGER STORY MAY BE STUDIED

Since the larger story of Pelé is that of the Windward archipelago, and also since it extends far back of the present into past geological time, it can only be understood or appreciated by those who can follow a brief statement of the simple geologic origin and history of the projecting and submerged members of the archipelago. This is based on the careful investigation of three lines of evidence which can here be only briefly summarized with the omission of the technical details. These are the physiography, including the processes of land construction and destruction, now in operation in the region; the stratigraphy, and the paleontology.

This is neither the time nor place to present the wearisome technical details of petrography, stratigraphy, and paleontology, on which scientific deductions are founded,† but if the reader desires to comprehend this larger story he must grasp the conclusions which will now be presented and summarized.

The processes of vulcanism, coral reef building, atmospheric degradation, and marine erosion at present in operation are the same as those which have taken place in the past and explain satisfactorily all the land building and land destroying operations that have previously taken place.

Thus topographic study of the visible forms of land and the contours of the adjacent sea bottoms gives much of the history of the islands and enables one to determine their relation or non-relation to other lands. The composition and stratigraphic arrangement of the rock material also assists in telling this history, while paleontology is a guide to the age of things.*

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* Whether this larger Caribbean volcanic mechanism is local or whether it in turn is but a part of a general condition of the entire center of the earth, from which all volcanic vents are fed, is also a subject worthy of far more consideration than it has received.

† Prior to the recent eruptions the writer, in cooperation with Professor Alexander Agassiz, made two expeditions to these islands in order to ascertain their geology and history.

In pursuing these researches and in the present paper he has endeavored, without prejudice in favor of any hypothesis whatsoever, to ascertain the actual facts. The detailed technical results of these studies will be published at an early date by the Museum of Comparative Zoology, Harvard University.

VAGUE THEORIES CONCERNING THE ORIGIN OF THE ISLANDS OF THE WINDWARD ARCHIPELAGO

Vague theories concerning the geographic origin and history of the islands have obscured the simpler volcanic story of the Windward archipelago. In fact, the origin of these islands has been interpreted by many writers, according to convenience, to fill in cracks and crevices existing in any argument they may have desired to maintain. Most of these have had little foundation in nature.

The oldest and most popular—the continental theory—is that the islands are the decadent remnants of a once much greater and connected continental land, and some have even asserted that they were the remnants of the lost Atlantis.

The continental theory is as old as tradition. Mr J. W. Spencer has revived it in a form in many papers. In these he has endeavored to prove that the islands are remnants of the backbone of a mythical Antillean continent, which connected the North American and South American continents in Pleistocene and earlier time.

Moreau de Jones, in the early part of this century, advanced what might be termed the orogenic theory. His hypothesis is that the Windward islands were a northeast spur of the Andean mountain axis, which, together with the Cumana mountains of Venezuela and the Greater Antilles, constituted a continuous mountain chain, and that the Lesser Antilles were the submerged peaks of this chain.

In addition to the above theories Milne and Doctor Tempest have recently spoken of the Windward islands as occupying the summit of a great fold in the earth's crust.†

Both the orogenic theory of Moreau de Jones and the continental theory of others seem to dominate, in the views of Professor Angelo Heilprin in a recent work.*

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* In each of these lines research data are still needed. In physiography the contour of the submarine areas can not be finally determined for lack of a few more appropriate soundings; in stratigraphy we are handicapped at the beginning by ignorance of the basic formation of many of the veneered islands and submerged banks which could easily be determined by drills; in paleontology the range of the Tertiary and Pleistocene fossils has not been clearly made out by the paleontologists on whom we rely.

Notwithstanding the incompleteness of knowledge, much has been done and enough has been found out to present some conclusions far more definite than certain eccentric theories which have been formulated, in some far-off study, without any foundation in nature at all, and which, strange to say, have found credence.

† The Geographical Journal, March, 1903, p. 266.

It may be futile for the writer to protest that the facts in nature do not support these views, and that their advocacy is obscuring a most simple and beautiful story in nature; and he will endeavor to show from a close study of the geologic evidence that the Caribbees proper are neither continental nor orogenic, but merely ocean-born volcanoes, built by the oft-repeated simple constructional volcanic process of pile-up, exactly like the recent event in Martinique, independent of the continents, and that they have never been connected with North America or the Greater Antilles. When thus understood and interpreted they present a most simple and interesting story.

To maintain our position we must present a more thorough review of the geology and geography of the islands than would be necessary were it not for the deep impression which the erroneous conceptions above maintained have made on literature.

GEOGRAPHIC DIFFERENTIATION OF THE WINDWARD ISLANDS FROM THE OTHER ISLANDS OF THE WEST INDIAN ARCHIPELAGO

In previous publications I described what is known of the physical geography and geology of the entire West Indian archipelago, of which the Windward islands are a part.†

In these papers I have classified the islands into four major groups of islands, namely: (1) The Bahamas; (2) the Great Antilles; (3) the South American islands, and (4) the Windward islands.

The first have been shown by Professor Agassiz to be submerged banks of unknown origin and composition, now covered by wind-blown coralline sands. The second are primarily true mountain folds, accompanied by old igneous intrusions, which have had many vicissitudes of uplift, subsidence, and deformation. The third are merely disconnected outliers of the northern edge of the South American continents which have been severed from their mother land as Long island has been severed from the United States.

The fourth group, which is the subject of the present paper, includes the Windward chain proper, which extends between the twelfth and nineteenth parallels of north latitude across the eastern border of the Caribbean sea from Porto Rico to the Orinoco.

To those who first look at the map and do not consider the minute geology, all of the Windward islands appear to be members of a kindred archipelago. This is not the case. In fact, however, they present several distinct geologic and physiographic subtypes. The Virgin islands at the north are Antillean, while Tobago and Trinidad are South American in natural relations.

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* Angelo Heilprin: Mont Pelé and the tragedy of Martinique, 1903, pp. 257-261.

† The geology and physical geography of Jamaica: Study of a type of Antillean development, based upon surveys made for Professor Alexander Agassiz. Bull. Mus. Comp. Zool. Harvard College, vol. xxxiv, Cambridge, September, 1899.

Cuba and Porto Rico, with the other islands of the West Indies, New York, 1898-1899.

From the remaining Windward islands—lying between the Anegada passage and Tobago—we must again detach Barbados,* as isolated from the chain in geologic peculiarity as it is geographically.

The remaining islands, the main Windward group, are geographically divisible into two parallel north-and-south belts extending the length of the archipelago. The eastern belt, composed of sedimentary rocks, includes Sombrero, Dog, Anguilla, Saint Martin, Saint Bartholomew, Barbuda, Antigua, the Grande Terre of Guadeloupe, Marie Galante, and Desirade.

The inner belt facing the Caribbean—the Caribbee islands proper—includes Saba, Saint Eustatius, Saint Christopher, Nevis, Montserrat, Basse Terre, Guadeloupe, Dominica, Martinique, Saint Lucia, Saint Vincent, the Grenadines, and Grenada. These, attaining heights approximating 5,000 feet in some of the islands mentioned, with Saba and Saint Eustatius at the north, which rise 2,820 and 1,950 feet respectively, and the Grenadines to the south, comprise the newest and highest summits of the Windward group.

CONFIGURATION OF THE ISLANDS

(See map, plate 43.)

Land heights and oceanic depths.—A proper conception of the origin and relation of these islands likewise requires a study not only of the land areas, but of the configuration of the adjacent slopes and bottoms. In interpreting their physiography the height of the islands should be considered from the ocean floor rather than sealevel, above which only one-third of the total relief is visible.

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* The island of Barbados, which thus rises from an independent submarine ridge parallel to the main Caribbee chain and to the eastward thereof, and its geological structure and composition present a singular dissimilarity from that of all the other Windward islands. Its fundamental beds, sands, and clays, called the Scotland beds, are intensely folded sediments, derived from the same unknown preexisting land and resembling similar rocks of Trinidad and Jamaica. These beds also show strong lines of folding, which must have taken place before Pliocene time. This fundamental formation again is veneered by the purest type of ocean formation known to occur anywhere, namely, radiolarian earths, which testify that the island was submerged to a great depth, veneered with radiolarian formation, and reelevated again. Still later, in Pleistocene and recent times, the island has gradually emerged from the sea coated with this veneering of coral reefs, these later movements probably being synchronous with those of the main Caribbee ridge. In its earlier Eocene history Barbados was South American and probably a peninsulate from the mainland. In its later Pleistocene and recent history it has participated in the oscillations of the Windward islands. (See map, plate 43.)

So far as the Caribbee ridge is concerned, the greatest land altitude is 5,000 feet and the greatest sea depth 17,064 feet. Hence the altitudes of the highest Windward peaks above the deepest adjacent sea depression are 22,064 feet. Thus about 29 per cent of the highest island masses are exposed above sealevel and 71 per cent submerged.

Surface configuration.—The above water physiography of the Windward islands is of two distinct types: (1) Primarily volcanic piles with typical slopes intensely etched by erosion, and (2) flat and terraced plains veneered with oceanic lime material. Some islands are composed entirely of one of these types and some of the other, while one or two are a combination of both. The outer chain of islands is largely of the flattened bench and plain type.

All of the inner belt of the Caribbee islands are primarily constructional volcanic piles. In most instances they present typical volcanic slopes, and sometimes distinct crater-like forms are evident. The relief of these piles also shows that there has been intermittent accretions—intervals of piling-up, alternating with intervals of quiescence and erosion.

There are other topographic features of the islands, modifications of the old constructional forms, at times almost destruction, which are all the result of the secondary processes of atmospheric and marine erosion.

Stream valleys are always numerous on the volcanic piles; in many cases they radiate out from the old summits. Except the delta plains near their mouths, on which the coastal villages are usually built, these exhibit no secondary topographic features, but are simple autogenous streams. These stream valleys are often profound and numerous, and sometimes ramify completely over the older piles.

Important features of the islands are the sea cliffs and wave-planed benches which surround them, the largest developed on the windward side, truncating their borders and breaking the continuity of the profiles. The benches are, of course, submerged and of shallow depth, and have clearly been produced by the action of the surf.

Still another topographic feature which can not escape the eye of even the most amateur observer is the conspicuous levels here and there traceable on the profiles or extending in horizontal benches, much like those now forming at the margin of the sea, some standing as high as 900 feet. From some of these old benches, as at Nevis and Saint Kitts, rise the more modern volcanic piles, while others apparently represent in the history of the islands an erosion stage, followed by uplift, and still others old wave-planed benches—volcanic piles which were first cut down, veneered with oceanic debris, and then uplifted above the level of the sea, so that they now present a surface of calcareous material.

Thus we see in the configuration of these islands the evidence of the great constructive processes in nature, volcanic pile-up, atmospheric and marine degradation, and simple lift-up and subsidence resulting from the mysterious and unexplained up-and-down regional movements of the earth's crust.

Submarine configuration.—The study of ocean floors is an enchanting subject, which, notwithstanding long contemplation, often results in the conclusion that beneath the veil of water there is concealed a physiography almost beyond our ken. Nevertheless, there are some features apparent in the submarine topography of the American Mediterranean.

We may conclude from what we know of the geology of the adjacent lands that the great Sigsbee Deep is merely the bottom of the basin-like cul-de-sac of the gulf of Mexico, while the narrow valley deeps of the Bartlett and Anegada type certainly suggest relationship to the adjacent Antillean folded land ridges. The narrow submarine ridges between Mole Saint Nicholas (Haiti) and cape Maisi (Cuba), Tiburon peninsula (Haiti) and Jamaica, cape Engano (Santo Domingo) and Porto Rico, represent the continuation of the folded mountainous ridges of the great Antilles, of which the eastward extending Virgin islands, rising from a common hundred-fathom bank, are also a continuation. When we seek to proceed farther, however, without presentation of data, there is great danger of becoming involved in erroneous deduction, and this is especially true of the bottoms adjacent to the Windward islands.

By carefully compiling and contouring the known soundings adjacent to the Windward islands a conception of the submarine topography may be obtained (see plate 43). This shows that the Windward area consists not only of the present islands appearing above the water, but certain extensive shallow submarine banks, very suggestive of former islands which have lost their land surface either through planation or subsidence.

Certain slopes and troughs may be made out here and there which throw some light on the former relations and lack of relations of the various islands and banks, but in general this submarine configuration shows the circular forms, steep slopes, and coalescing bases of volcanic piles in continuation of the profiles of the projecting islands.

Inasmuch as this submarine configuration has been used as an argument on which to base the supposed existence of a former continental connection—the supposed Antillian bridge—let us consider for a moment what connections could occur in the configuration should the relative position of the sea or land level be changed. The 100-fathom line connects many of the islands in groups showing natural relation, and this contour alone suggests what may have formerly been connections between some of the islands and banks. An elevation of the land or lowering of the sea of 100 fathoms (600 feet), for instance, would largely reduce the number of islands. It would connect all of the Virgin islands with Porto Rico, where they genetically belong, but these islands and the entire Great Antillean province would still be separated from the Windward chain by the Anegada trough, an abyss of over 2 miles in depth. This 100-fathom contour would gather Anguilla, Saint Martin, Saint Bartholomew, and other islands of that vicinity, such as Dog, Seal, and Tintamarie, into a common land larger than the present area of Trinidad. To the southeast Barbuda, Antigua, and the adjacent reefs and rocks would constitute another land area nearly as large. The great Saba bank to the southwest of Saba would appear above the water as an island almost as large as Guadeloupe.

Saint Eustatius, Saint Christopher, and Nevis, now separate islands (just as Saint Lucia would constitute a number of islands if lowered a similar number of fathoms), would stand up as a continuous volcanic ridge. Montserrat would still continue as a solitary volcanic peak. Guadeloupe, with Grande Terre and Desirade, would be a single island, but not connected with Marie Galante and the Saintes, which would remain isolated islands.

Martinique would be doubled in area by an increased land to the north from the emergence of a submerged calcareous peninsula extending in that direction, producing conditions exactly analogous to those now in Guadeloupe.

The numerous Grenadine islands would be united with Grenada in a long volcanic ridge resembling the Saint Christopher ridge. Montserrat, Dominica, and Saint Lucia, however, would continue in their isolation as simple constructional volcanic piles separated from the other islands.

A little island like Barbados would appear nearly 100 miles north of the latter, and the little rock of Aves would be considerably increased.

The consolidation of islands, it will be noted, would nearly all occur at the northern end of the chain. To the southward of Antigua a change of 100 fathoms would make no material difference in the present land areas except to unite the hundreds of little headlands constituting the Grenadines.

The 500-fathom line (3,000 feet) collects the islands into four groups: (1) Saint Croix; (2) all the other islands and banks southward to Dominica, inclusive; (3) the island and banks of Martinique, and (4) Saint Lucia, Saint Vincent, and the Grenadines.

An elevation of 1,000 fathoms (6,000 feet) would connect all of the Windward islands as a long peninsula extending out from South America, but a strait would still exist between this peninsula and the Virgin islands, between Cuba and Yucatan, between Haiti and Jamaica and Cuba, although Cuba would be connected with the Bahama banks and Florida.

The three Windward ridges.—In studying the further meanderings of the 1,000-foot submarine contour a most interesting configuration is revealed. The entire mass of land and sea bottom within this contour is peninsulate to South America and is still separated from the Great Antilles, just south of Virgin islands and Porto Rico, by the Anegada trough, a narrow canal the bottom of which is now over 6,000 feet beneath the level of the sea. Hence, in order to establish any previous connection between these islands and the Great Antilles or North and Central America, it will have to be proven that the Caribbean sea bottom has subsided to at least this depth of 6,000 feet.

This arrangement of the submarine banks and islands relative to South America, furthermore, presents a remarkably tri-peninsulate arrangement, consisting of three distinct elongated ridges, separated by deeps, projecting northward from the South American continent, which may be termed the Barbadian, the Caribbean, and the Aves ridges, respectively, from east to west.

The easternmost or Barbadian ridge extends from Tobago, Trinidad, and South America northward only about one-third the total circumference of the Windward segment. This ridge appears above the sea only at the site of the island of Barbados, but is represented, as shown on the contour map, by two banks which come within 100 fathoms of the surface to the north of that island.

The Aves ridge, to the westward, reveals only one tip of land above sealevel. This is the small island of Aves (Bird island), about 150 sea miles west of Guadeloupe, to the north and west of which there is a rapid deepening of the water. Its southern extension, as indicated by soundings, continues definitely nearly to north latitude 13 degrees, from which point its connection with the South American bank is indefinite, owing to lack of soundings, as shown by the dotted lines on the map. The Aves ridge extends more than half the distance of the entire length of the Windward segment between the Anegada passage and the South American coast. To the west this bank rapidly deepens in a submarine escarpment of 2,000 fathoms in less than 70 miles, somewhat similar to the manner in which the Barbadian ridge scarps sharply toward the Atlantic basin. Nothing is known of the geologic structure of this ridge, and the only way it could be determined would be by a deep boring on the island of Aves.

Of the three ridges the Caribbee, or central one, alone projects considerably above the sealevel, and along this ridge are arranged all of the present true volcanic islands.

This central Caribbean ridge, from which the islands arise, as circumscribed by the 1,000-fathom submarine contour, may be divided into two sections, south and north of Martinique, respectively. The southernmost of these, made up of Saint Lucia, Saint Vincent, the Grenadines, and Grenada, consists of a simple line or chain of islands.

The northern half is wider, more complex, and suggestive of an archipelago. In addition to the simple line of volcanic islands of Martinique, Dominica, Guadeloupe, Montserrat, Nevis, Saint Kitts, Saint Eustatius, and Saba, it includes Saint Croix and all the outlying Anguillan, Antiguan, and Saba groups of banks and islands.

In the southern section the 1,000-fathom contour closely follows the base of the volcanic islands. In the northern section it diverges and widens so that it encloses an extensive oval area of a mean breadth four or five times greater than that of the southern section.

Perhaps the origin of this remarkable submarine configuration will be suggested as our narrative proceeds.

VOLCANIC ORIGIN AND ARRANGEMENT OF THE MATERIAL OF THE ISLANDS

The composition of the rock material of the main group or central ridge of the Windward islands is simple. All the islands except Barbados, which is different in its lower formation, are primarily composed of volcanic ejecta derived from the earth's interior, supplemented by marginal deposits of lime material extracted from pure sea water by marine animal organisms which lived and died around the shore of the preformed volcanic piles. It is important to note that there are no granites, ancient sedimentaries, transported drifts or gravels, or other material whereby any former extensions or continental relations may be established. Hence the islands are oceanic in origin and non-continental.*

Even in Jamaica, Haiti, Porto Rico, the Virgin islands, Saint Martins, Saint Christopher, and Antigua volcanic tuffs constitute the basement initial rocks of the island, so far as known, and are bordered by a peripheral fringe of local oceanic sediments.

Outwardly the islands are either composed almost entirely of volcanic material or of a volcanic basement partially veneered with sea-made lime debris or, in the case of the lowest and least conspicuous, of a presumable volcanic basement entirely veneered with sea debris (calcareous islands). These three types are exemplified in Saba, Antigua, and Barbuda. The main Caribbee chain, like Martinique and Saint Vincent, consists almost exclusively of extruded volcanic ejecta piled up during ages of intermittent eruption.

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*Oceanic islands never, as a rule, contain any of the typical rocks of continents—*i. e.*, sedimentary strata, metamorphic rocks, or such acidic rocks as granite.—Sir John Murray, International Geography, p. 62.

Antigua, Saint Croix, and the Anguillan group of banks of the northern section in their structure, composition, and origin present a foundation of volcanic tuffs and agglomerates similar in composition and nature to rocks of the present volcanic Caribbees. It is not unreasonable to infer that Barbuda, Anguilla, Dog, and other small calcareous islets composed entirely at their surface of oceanic material likewise rest on volcanic basements.

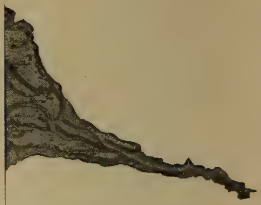
No sources other than the earth's interior and pure oceanic water have contributed matter to the land masses of the Windward islands. In the clear sea waters surrounding the Windward islands invertebrate organisms abound, which are constantly concentrating from the sea water the carbonate of lime which constitutes their skeletons. Foraminifera, molluscs, and corals live and die on the shores and slopes, contributing their load of solid material to the land masses. The quantity of organic material, although but small in comparison to the volcanic ash already exposed in the sections of the islands, is large, while in the submerged slopes of the ridges a still greater quantity, though unexposed, undoubtedly occurs.

This process of rock-making by organisms, although not given sufficient consideration in text-books, is well known to all students of coral reefs and tropical oceanography. Its operation in the West Indies has been fully described in the writer's report on Jamaica.

The geologic structure of the Windward islands is likewise exceedingly simple and owes its arrangement chiefly to volcanic processes. It consists primarily of constructional volcanic piles, with material arranged at various degrees of inclination, in accord with the well known laws of the angle of rest and submarine beds of sedimentary material. Deformation of any kind except local land slips is inappreciable. The only modifying structural processes are those of unconformities produced by littoral marine erosion, the deposition of organically extracted lime accretions on the planed-off volcanic foundations, and the oscillations of regional uplift which are supposedly connected with vulcanism. There should be some instances of local folding or faulting, but trustworthy evidences of these phenomena are lacking.

It is true that in the east-west Antillean trend to the northward there are great fault lines, and the same may probably be true along the east-west South American trend. In Barbados, to the east, we find serious pre-Pliocene deformation, but in the main north-south Caribbee ridge no trace of marked displacement or fissuring by deformation has been discovered.

If fissuring exists of a size sufficient to feed the roots of the Caribbee volcanoes with water, as alleged by some recent writers, or if these have



existed for countless millions of years during which these volcanoes have been active, evidence of their presence is conspicuously absent from the geological structure.

ANTIQUITY OF THE VOLCANOES AS ATTESTED BY THE AGE OF THE ROCK MATERIAL

All the evidence indicates that the present vulcanism is the continuation of that which began early in geologic history, and that the main mass of the material composing the island was ejected long before the dawn of human history.

The configuration and the structure of the islands show that their volcanic history extends, at least, as far back as Eocene time, if not Cretaceous. In Jamaica, Haiti, and Porto Rico, as well as throughout the Virgin islands, the basement formations of the islands (of Cretaceous and Eocene age) are volcanic hornblende-andesite tuffs exactly similar to those now being erupted from Pelé. Furthermore, while the primary configuration of all these islands is constructional—largely due to extensive piling-up—the present minor details of configuration, expressed in steep coastal bluffs, benches, slopes, and canyons, are modified by erosion, which has required considerable time for development. The crater shapes are usually secondary summit features located on larger, older, eroded volcanic piles, which have lost the features of their original contour through erosion. The newly built-up crater at Pelé is an excellent illustration of this fact. The grand Soufriere of Guadeloupe is another.

A direct proof of the antiquity of this vulcanism is also shown in the tuffs of Antigua, which are very old, as they are overlapped by supposedly Eocene sediments. Pervis* has shown that these tuffs are identical in lithologic composition to the ejecta from the volcanoes of Guadeloupe in the present century.

In Guadeloupe we have also much physiographic evidence concerning the antiquity of the volcanic action. This island is composed of two parts, of about equal area, separated by a shallow creek or strait, Riviere Salee. The most western of these islands (Guadeloupe proper) is a typical volcanic pile of the main Caribbee chain and is thoroughly mountainous. The eastern area (Grande Terre) is an elevated constructional plain, composed of calcareous sediments of Pleistocene age, overlying a platform of planed-off volcanic tuffs, etcetera.

The whole geological history of the Caribbean volcanic island is illustrated by this beautiful map (made by the French) of the double island of Guadeloupe (see plate 44). The island is composed of two great

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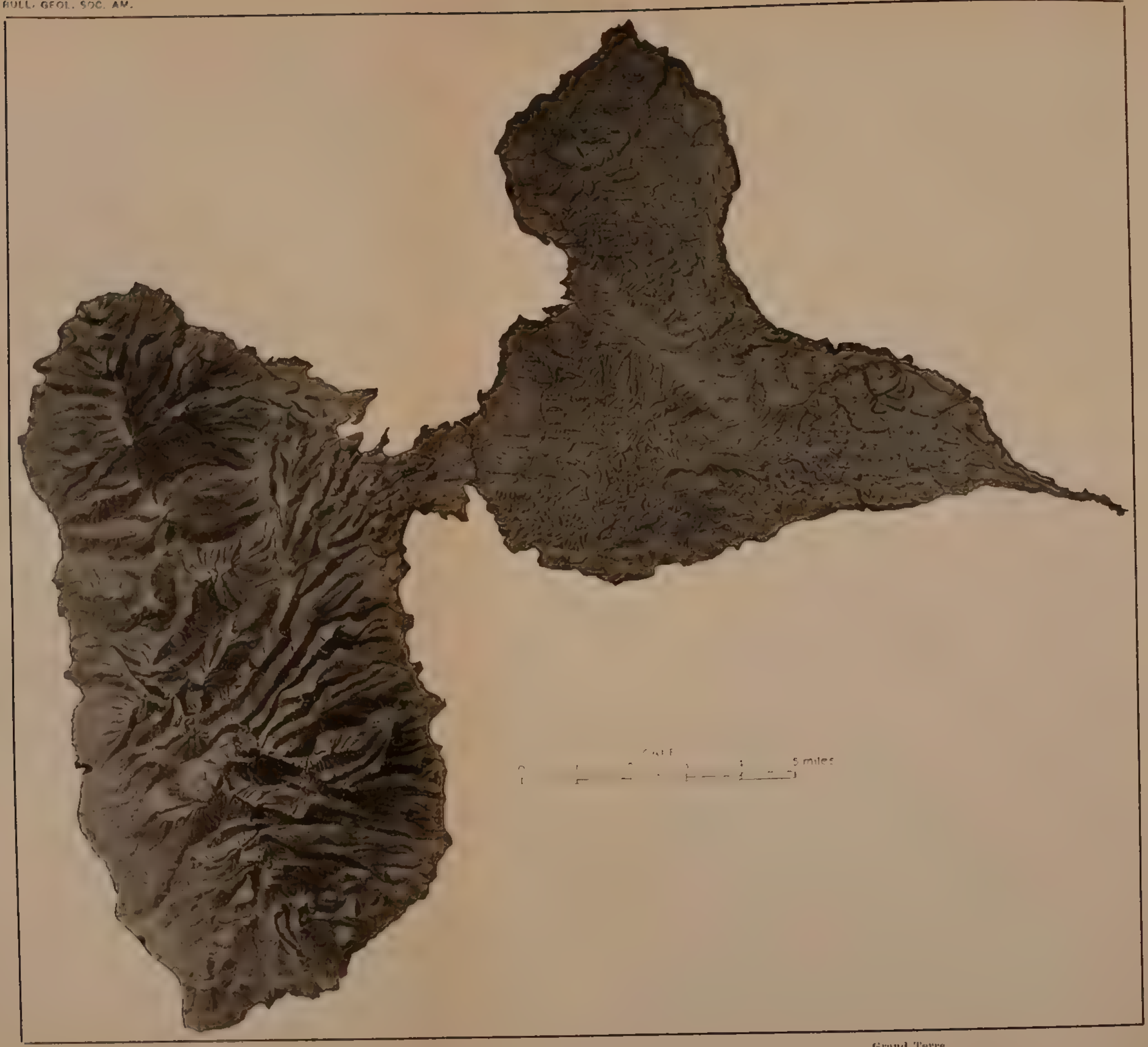
* Geology of Antigua.


SCALE
0
1
2
3
4
5 miles

Guadeloupe

Grand Terre

DOUBLE ISLAND OF GUADELOUPE

volcanic piles which grew up above the sea. The one on the left is a volcanic mass which still exhibits its constructional forms, although it is being baseleveled to the sea by erosions of the numerous streams radiating away from the summits, as can be seen by flattening profiles near the coast. There are many old volcanic vents, six or seven of which are recognizable.

Towering above these near the south end is the Soufriere, altitude 4,868 feet, the highest peak of the Windward islands. This is a live volcano, emitting steam and sulphur fumes, and is the most dangerous and frequent erupter of the Caribbean group. It is clearly the latest chimney of a group of successive chimneys which through ages past have been building up the great ash pile which constitutes the island.

On the right is the low, terraced, and flat-topped island of Grande Terre, surrounded by growing coral reefs. It, too, was once a volcanic pile, probably as high as Guadeloupe; but in Tertiary time it was worn down to the level of the sea by erosion (largely marine), and through regional subsidence its truncated top sunk over 200 feet beneath the sea. Corals and other invertebrate life grew on it, and it was veneered thereby with a thick coat of limestone. In late, almost recent, geological time it (together with Guadeloupe and all the Windward islands) was re-elevated by another regional movement to 300 feet above the sea, and its surface is again being plowed and removed by erosion wearing it down toward baselevel.

While these processes of atmospheric and marine destruction are tearing away at the surface the crater of Soufriere is, at intervals, building up by eruption of new matter from the earth's interior. Thus the great processes of nature continue, the sum total of which is the addition of matter to the thickness of the earth's crust by volcanic contributions from its interior.

The great indentation of the coast line on the northeast shows how the trade-wind surf has eaten away that portion of the once nearly circular island.

The above phenomena are further illustrated in the half-tone plates. Plate 45, figure 1, illustrates the more recent piles at the summit of Guadeloupe. Plate 45, figure 2, shows the profile of the volcanic pile, and plate 46, figure 2, shows the physiography of Grande Terre, exhibiting two of the notable levels—a higher one in the background and a bench in the foreground, on which the village is built. Growing reefs may be seen where the water is breaking in the sea. Plate 47 shows the destructive character of the marine ocean, which is planing away the lee shore of both islands.

To the east of Grande Terre is the small terraced island of Desirade,

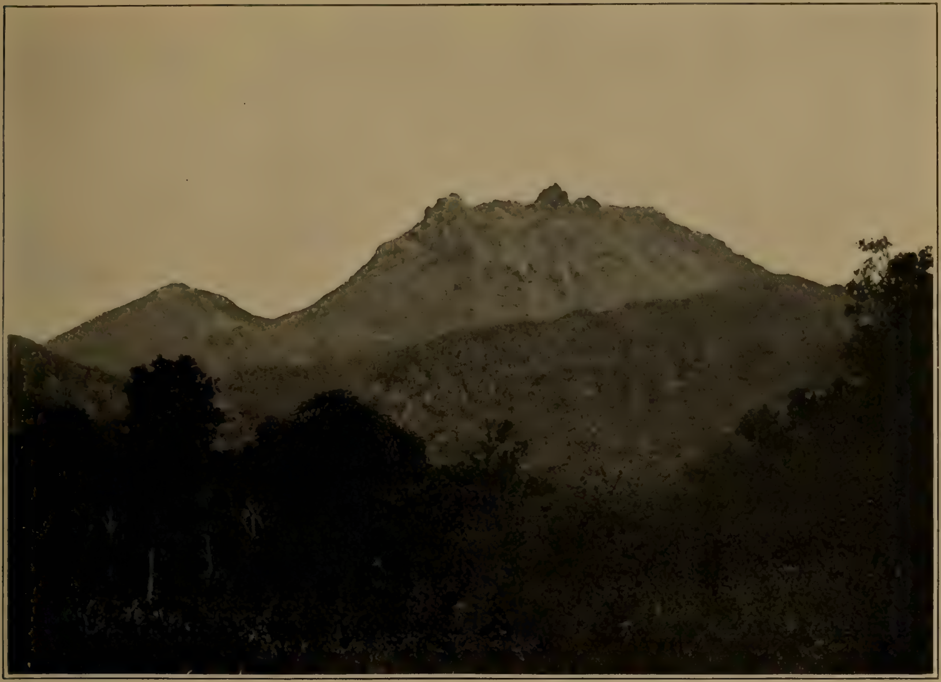


Figure 1.—La Soufriere, Guadeloupe Island
Highest volcanic pile of the Windward Islands

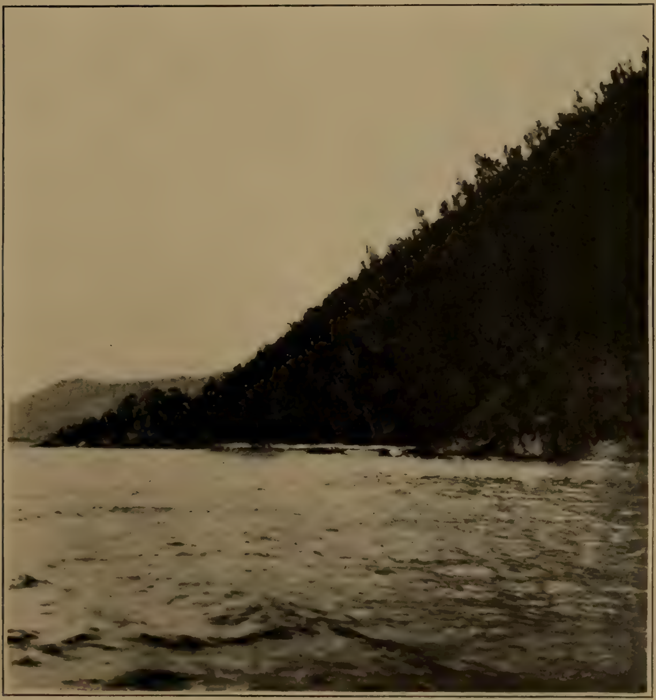


Figure 2.—Northeast Coast of Guadeloupe Island Showing Volcanic Profile

LA SOUFRIERE AND NORTHEAST COAST OF GUADELOUPE ISLAND

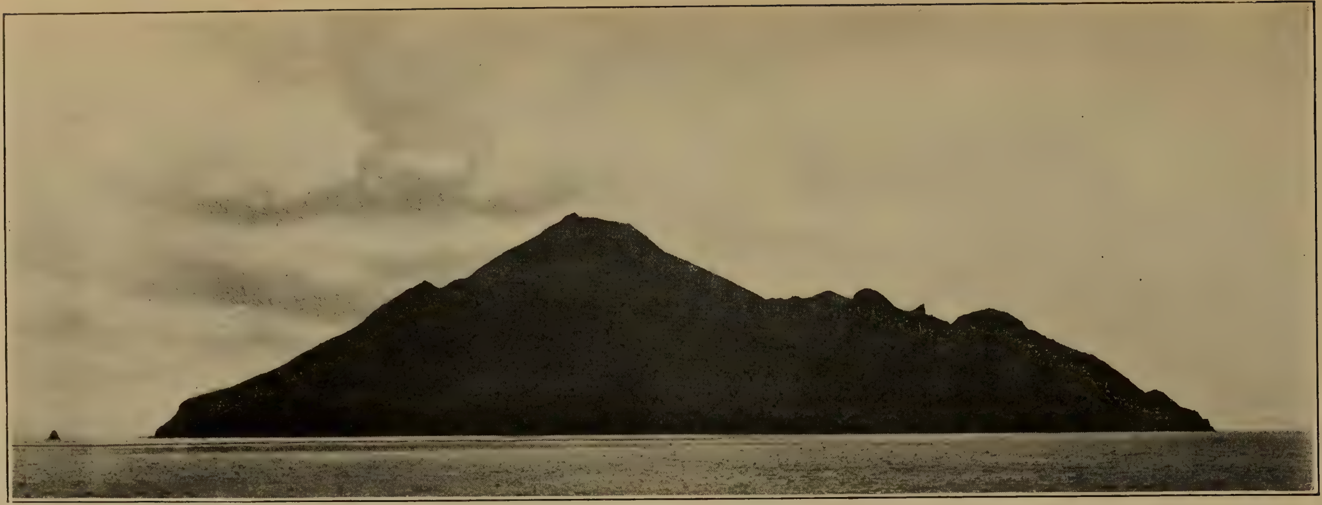


FIGURE 1.—TYPICAL VOLCANIC PILE—SABA ISLAND FROM NORTHEAST
Copyright photograph by F. E. Huddle

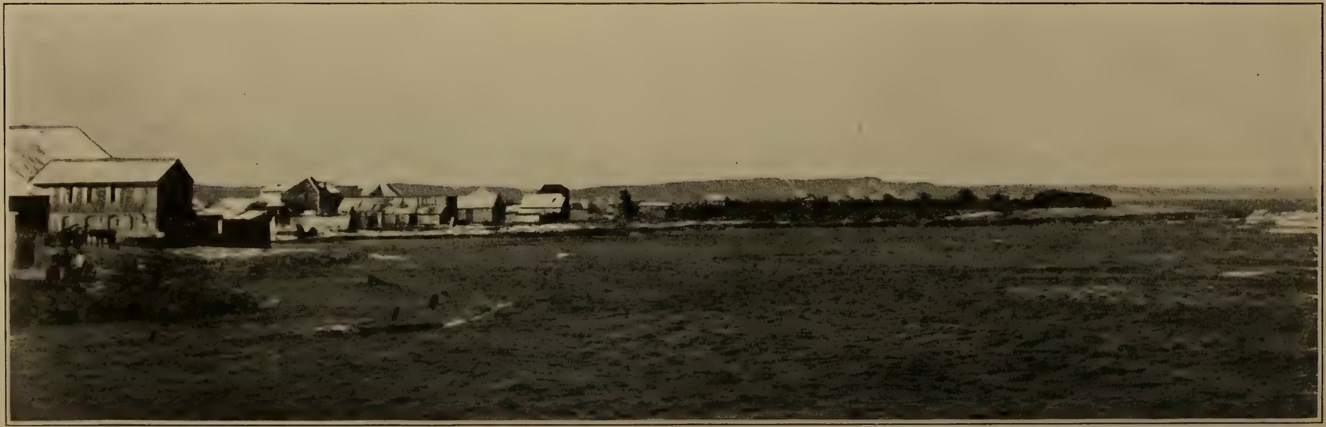


FIGURE 2.—ELEVATED BENCHES ON NORTH COAST OF GRAND TERRE, GUADELOUPE ISLAND

SABA ISLAND AND ELEVATED BENCHES ON GRAND TERRE, GUADELOUPE composed entirely of organic material, which with several other islets stands above a shallow submerged platform extending out from the southeast end of Grande Terre and Basse Terre. Grande Terre was undoubtedly once a volcanic pile like Guadeloupe. It was planed down to sealevel by the waves, covered with shells, and reelevated to its present position, all of which processes required time.

To the southward of Grande Terre is the island of Marie Galante, of the same topographic and geologic type. This archipelago exhibits a long battle between the processes of volcanic pile-up, marine degradation, elevation, and subsistence since the original vulcanism began.

In Saint Christopher, Saint Eustatius, Guadeloupe, Martinique, Saint Lucia, and Grenada patches of disturbed fossiliferous beds of Pleistocene or recent age are occasionally found interbedded in volcanic debris on the lower seaward slopes at altitudes of 200 to 900 feet above the sea, showing that vulcanism existed in or prior to Pleistocene time, and that the volcanic piles themselves participated in the regional uplifts, elsewhere described. The fossils enumerated are hardly older than Pliocene, and are most probably Pleistocene, and their position around the edges of the piles show that the great mass of the islands were ejected in previous epochs.

In general it may be stated that with the exception of Cuba the oldest and nucleal rocks proven in the Great Antilles and Windward islands are volcanic ejecta similar in material to that of the present ejecta, and that with the exception of Barbados * all the accompanying sedimentary rocks are either the local sediments derived from these old volcanoes or from the remains of oceanic animal life which lived on their slopes.

More direct and scientific proof of the antiquity of these volcanoes is found in the record of the fossils of the sedimentary rocks here and there veneering the volcanic piles or interbedded with them. The calcareous and sedimentary formations of the Windward islands are all Tertiary, Pleistocene, and recent age.†

HOW THE OCEAN TEARS AWAY AS THE VOLCANOES BUILD UP

The intelligent traveler sailing down the islands may see, if he knows how to see, other things going on, hand in hand, with the volcanic eruptions, equally important to an understanding of the larger story of Pelé.

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* The basement series of this island, as I have elsewhere shown, is South American in its affinities and unlike the Windward islands.

† These may be divided into three distinct age categories:

1. Older beds represented in the northern islands of Saint Bartholomew, Antigua, and possibly Saint Martins and Saint Christopher, containing fossils which may be temporarily referred to the Eocene.
2. Marly formations found in Antigua, Saint Croix, Grande Terre, Guadeloupe, and possibly Barbados, which have been referred to the Oligocene.
3. Indurated calcareous muds, marls, and shell debris and true reef rock of an age so recent that they cannot be paleontologically differentiated, but probably include the Pliocene, Pleistocene, and recent period.

While looking upward at the volcanic clouds, adding heights to the mountains with each new layer of dropping ash, he should not fail to note the deep fonds or V-shaped gorges radiating from the summits and grooving the slopes of the pyramidal cones which have been cut by the rainfall, the gnawing surf undermining the great cliffs which truncate the profiles of the mountains as they reach the sea, and the growing and dead shell and coral rock which cover the sea borders. Nature is tearing down as well as building up. These are the processes of the world at work, and it is important to consider them.

The present islands represent merely the remainder or algebraic sum of a long series of volcanic constructional additions and atmospheric and oceanic destructional subtractions. These processes of land building and destruction at present in operation are identical with those of the past and tell the history of the Caribbees. They not only illustrate the origin and growth of oceanic islands, and through them the embryonic growth of continents, but also convey a suggestion of the totality of the actual quantity of matter contributed from the earth's interior and which has been piled up around these old vents.

Of course the chief constructive factor of these processes has been volcanic pile-up, like the recent eruptions of Pelé, many times repeated. All the islands owe their origin primarily to this heaping up of material, projected to the surface through volcanic vents, even though within human history there have been but few eruptions in the Caribbee islands.

In fact, it had been so long since any explosions had occurred in the Caribbee islands that most geographers,* as well as the inhabitants, were of the opinion that the forces which produced them were spent, and classified the islands as extinct volcanoes.

But the tocsin of Pelé awakened us, and we now realize that the processes of vulcanism recently so intensely manifested in some islands have also been actively in operation in all the other islands, even those which are not now ordinarily classified as volcanic, and it is even probable that the calcareous islands and banks, which now show no vestiges of volcanic phenomena, are old volcanic piles which have been cut down by the sea, veneered by oceanic debris, and reelevated to their present location. Although these eruptions have been but few in human his-

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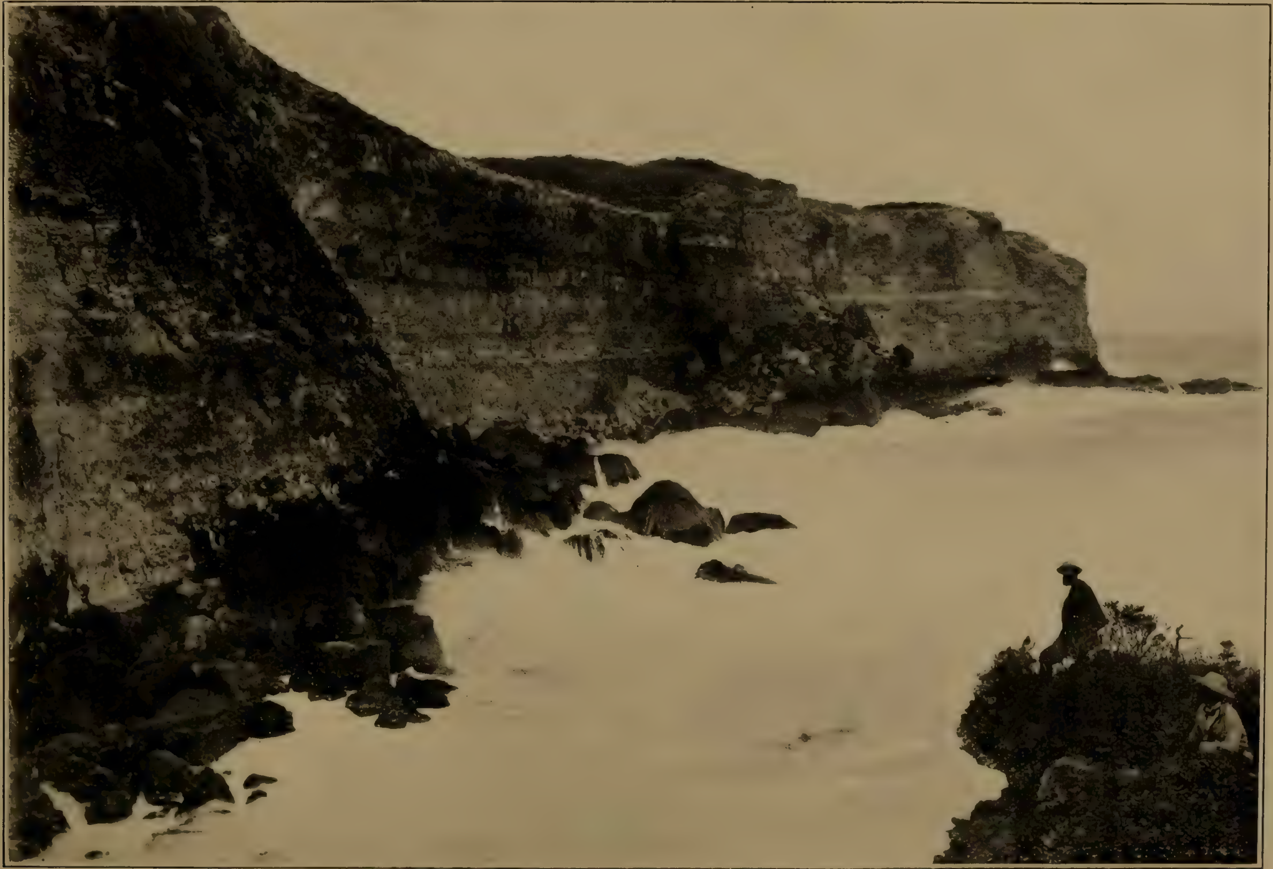
* It is one of the most lamentable admissions of our lack of geographic knowledge to state that no traveler, geologist, or explorer, previous to the disaster of 1902, has ever systematically visited all these vents and craters or published anything about them as an entirety.



PORTE D'ENFER, GUADELOUPE ISLAND

Showing destruction of land by marine erosion, also old level of elevation of marine calcareous coating of islands

tory, they have been occurring throughout a vast interval of time, and hence in the aggregate have been many.

If the quantity of material actually contributed from the earth's interior and added to this surface, as witnessed by the 1902 eruption of Martinique and Saint Vincent, was enormous, what must its aggregate have been in the past?

If "water gas, which, ultimately escaping as steam, has been estimated at $\frac{999}{1000}$ of the whole cloud that hangs over an active volcano," as alleged by Geikie,* then the solid matter discharged into the air is but $\frac{1}{1000}$ of the volcanic cloud. It has already been shown, however, from observations of the recent eruptions of mont Pelé and Saint Vincent, that the larger proportion of the solid matter escaping as dust from the craters was distributed by the atmosphere for hundreds of miles around instead of immediately settling down around the vents. If $\frac{9}{10}$ of this $\frac{1}{1000}$ of solid matter is wafted away from the island piles (and this estimate is small), then it is evident that the volcanic rocks and ashes piled up around the vents and constituting the present islands, without any consideration of the wear and tear of surface erosion, can represent only $\frac{1}{10000}$ of the actual matter which came up through these vents from the earth's interior. Hence these relatively large islands represent only an infinite fraction of the total solid matter discharged by these old vents during long eons of time. But even this little fraction must be again subdivided, for destructive forces long in operation have been tearing away almost as fast as the volcanoes could build them up.

The trade winds, blowing with full severity against the eastern shore, create an enormous surf, which is constantly and continuously eating away the shore line and cutting down below sealevel the volcano-built islands. This destructive work and its combative attacks on the growing areas of land is a most instructive feature of the region. In fact, this destructive process is secondary only to that of the constructive process of volcanic pile-up, and the present aspects of the islands are chiefly a result of the endless battle between these agencies.

The power of the sea to plane off in horizontal directions obstacles projecting above it is everywhere seen. Huge cubes of rock which have fallen into the sea near Bathsheba, on the Windward coast of Barbados, have been completely cut in two. The processes of the sea in cutting through these rocks by attacking them at surf line is but an illustration of how larger islands have been completely reduced to submarine banks.

A superb example of sea destruction is the bight known as Porte

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* Text-book, edition 1903, p. 266.

D'Enfer, on the north coast of Grande Terre, Guadeloupe, where the surf of the ocean is undermining cliffs 200 feet in height (see plate 47).

The eastern border of Martinique is cut into hundreds of shallow bays and inlets by the strong action of the heavy surf, which everywhere on that side prevents free navigation, and the contour and topography of the adjacent sea border shows that this land once extended to the outer margin of the islands which now border it.

On the leeward shore of the islands similar work is going on all the time, although the tremendous biting effect of the surf is not so great on the leeward shore. It is, nevertheless, sufficient to produce a well defined horizontal indentation into the shore, which results in the undermining of the cliffs. The lee shore of all the islands exhibits the result of this process.

If islets, such as these constituted by the Barbadian rocks, can be thus destroyed, it is not unreasonable to assume that the same processes may reduce larger areas of land to low benches below sealevel, and if there is no further elevation or addition to the masses of the islands now projecting above land these same processes can ultimately plane them all down to a level below the surf and wave action of the sea.

On the windward side of all the islands to a large degree and the lee side to a smaller one there are low shallow benches and banks, which have clearly been made by this process. It is not unreasonable to believe that great areas of submarine banks without any land surface, like those of the Saba banks or the great banks which extend as a submarine shoulder for 100 miles north and east of Martinique, may have once been land which has entirely disappeared largely by this process of cutting and planing by the sea.

In fact, if no other process were in operation than this one of destructive surf planation, it alone would account for the dissection of the various archipelagoes of the Windward group arising from a common bank, such as the Virgin islands, the Grenadines, Guadeloupe, and Antigua.

That the planation has continued for a long time past as an important factor in producing the present configuration of many islands is directly shown by several examples. All the islands of the Grande Terre, Guadeloupe bank, represent an old volcano pile larger than the present island of Martinique, which was planed down to and below sealevel in Tertiary time, veneered with organic material, and afterward elevated to its present position. Such, probably, has been the case with Barbuda, Anguilla, and many other of the small calcareous islands. He who indulges in speculation would find no difficulty in conceiving that the great Saba bank owes its present configuration to the same causes, aided by slight changes of level. Even the Bahamas may be similar remnants of old volcanic piles.*

OSCILLATIONS OF THE OCEAN'S BOTTOM

There has been still a third and less understood process at work in producing the present configuration of the Windward islands. This is the great process of regional movement (uplift and probably subsidence) of the sea bottom, together with all the islands resting thereon—veritable heavings of the bosom of the earth.

These movements are clearly and unmistakably recorded in the configuration of elevated reefs, benches, and terraces already mentioned. By these processes banks which once existed only below the water have been elevated into islands, and islands which showed but slightly above the water have been lifted still higher, and all of the islands, of whatever composition and structure, both volcanic and sedimentary, have participated in these movements.

Plains and terraces which originated by marine erosion at or below sealevel are now lifted into terraces and island summits, in many cases covered by growths of coral reef or shell debris. Old baselevels of erosion, which represented land planed down to sealevel, are now similarly lifted and again undergoing destructive degradation. Colonies of sea life, which inhabited the marginal waters of the ocean at the shore of the volcanic piles, are now found at heights of from 100 to 900 feet above the sea, resting on the great masses of the volcanic piles which have been lifted with them.

Concerning the elevations, the evidence is sharp and clear, the subsidences are only inferential, but nevertheless probable.

Owing to the slowness of these movements, it is impossible to measure them or to state with positiveness whether they are in operation at present, but that such is the case may be inferred from the recent character of the upraised benches and the unmistakable records of their long continuity in the past.

In the writer's work on Jamaica, in part V, "Changes of level in the West Indies," attention is called to the evidence of uplift and subsidence recorded in the Greater Antilles. Darwin and others have long since described similar phenomena on the Pacific coast of South America. Writers have also shown that elevated benches and terraces conspicuously mark the periphery of the European Mediterranean.

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* Moreau de Jones, in 1816, discovered that the calcareous outer islands of the Caribbee chain rested on igneous formations. He showed that these islands were mostly situated to the windward of the volcanic group, and that even in the volcanic islands, where calcareous formations were also found, the latter were mostly on the Atlantic side. In fact, there is evidence that the vents of volcanic activity have migrated westward slowly during geologic periods, as the sea planed away the Windward piles.

That these movements have been regional and not orogenic is testified by the harmonious evidence that all the islands participated in them. At present the cause of these great uplifts and subsidences can not be interpreted. They can in no way be ascribed to sudden and disastrous catastrophies accompanying the violent disturbances popularly supposed to be associated with volcanic eruptions, although we can not say that they are not gradual after effects.

Associated with these phenomena are the problems of the origin and meaning of the triple submarine Windward ridges—the Aves ridge to the west, the Barbadian to the east, and the deep troughs separating them from the great central ridge from which the present Caribbee volcanoes apparently arise.

Who can explain the mystery of these troughs and ridges and their part in the history of the Windward islands? It is a legitimate inquiry to ask if their present condition and relations, like the great changes of level noted, may not be isostatic results of vulcanism—that is, if they could have been the result of adjustment of the crust to interior vacuities created by the extrusion of the great volcanic piles. The cross-section of this tri-peninsulate configuration might be the basis of a hypothesis that the present conspicuous Caribbee ridges are piles on the axis of a subsiding dynamic valley or line of weakness between the older ridges. Such speculations present enchanting fields for reflection, but they carry no supporting data or convincing conclusion.

Some writers have even gone so far as to suggest that these changes in the level have been those of the sea water rather than of the land and bottoms. It may be that the great oceanic waters have changes in volume, but as yet there is no tangible evidence of it.

SUMMARY

It must be apparent now that the conceptions as to the continental origin of these islands, mostly created to uphold some preconceived theory, without being based on adequate geologic research and which have confused the pages of scientific literature, are erroneous. Analysis of the geologic history of these islands fails to support one of the many complicated theories which have appeared in print concerning their continental origin.

If they were once a part of the Andean and Antillean mountain systems, a great fold or a continental bridge, now destroyed by subsidence, some evidence of these facts would have been found by investigation undertaken without preconceived prejudice or theory.

A great subsidence of 6,000 feet, leaving the present islands as the tips of a submerged continent, must be proved to have occurred in the Windward islands in late geologic time in order to give the least support to the continental theory with its mysterious drowned ridges. No evidence of such an extensive subsidence would have been found in the submarine topography.

Considering all the lands and bottoms within the 1,000-fathom contour, it is impossible to find any evidence of former existence of a united body of land which has been dissected into fragments, as has been suggested.

All the evidence concerning the Anegada channel, one of these alleged rivers which separates the Windward Island group from the Virgins by the 500, 1,000, and 2,500 fathom contours, from Porto Rico and the Virgins, is that it is one of the orogenic troughs of the Antillean system.

The Saint Lucia and Martinique channels, on the other hand, occurring between great extrusive volcanic piles instead of being drowned rivers, are constructional valleys of coalescence between slopes of adjacent volcanoes. It is impossible to find any evidence that a subsidence of 6,000 feet, which would have been necessary to dismember the alleged Antillean continent, has taken place or that the sea bottoms ever stood 6,000 feet higher than now, as they must have stood to make these imaginary connections.

The narrowing, steep, leeward submerged profiles of the volcanic Caribbees south of Guadeloupe are constructional piles exactly similar to those of their continuation above the water and not those of old continental river valleys, while the banks extending to the windward are clearly the work of marine planation proceeding in the past as it is today.

The elaborate tectonic theory maintaining a structural connection between the Venezuelan, Antillean, and Windward ridges falls before an analysis of geological facts. It is impossible to connect the east and west Antillean and Venezuelan folds and faults with the main Caribbee ridge, and all the evidence shows positively that they did not connect. The only hypothetical connection which could be established between the Venezuelan, Antillean, and Windward groups would be via the Barbadian ridge, and such a task would require a most imaginative mind and entire disregard of facts.

Proofs of great rock folds postulated by Milne and Anderson as a part of his " macroseismic " theory are also absolutely lacking. Instead, the Caribbee volcanic ridge apparently rises from a trough between two more ancient ridges. There is no evidence of folded structure at all except the easternmost of these, the Barbadian. It is utterly impossible to connect the volcanoes with crustal movements resulting from any sedimentary loads.

These theories all disappear before the indisputable proof that the islands are simple constructional volcanic piles which have grown above the ocean floor around persistent volcanic vents, oceanic in origin, and which have never been united as a whole with each other, much less with the North American continent.

It is better now to abandon these unfounded continental theories and to concentrate our attention on what the islands really are—merely volcanic piles, as oceanic (non-continental) in origin and relations as the islands of the Pacific. These volcanoes are the most ancient feature of the region and typify a persistent field of vulcanism which has existed as far back in geologic time as we can see in the locality, and which existed prior to the formation of any of the secondary local sedimentary rocks which now veneer the volcanic piles, and which would not have accumulated had it not been for the volcanic piles in the oceans.

The simple fact that all the islands, excepting Barbados, are or have been old volcanic piles born of the ocean, as most volcanoes are, is the basis of the entire history of the Windward islands. Volcanic eruption, marine planation, secular upheaval, and lime-making oceanic life—these are the simple factors which have built up these islands, planed some of them down below sealevel, and lifted up the lime-covered banks into calcareous veneered islands again.

Each of the Windward islands represents a chimney, past or present, of the great volcanic mechanism of the earth's interior, where dynamic substances, usually banked in below, have now and then, through the long years of geologic time, occasionally broken forth and added strata of ashes to the preexisting surface. Hence it is that the present islands, projecting and subterranean, ever diminishing by atmospheric and marine erosion, represent only infinitesimal fractions of the total quantities of material which has been erupted.

In comparison with the vast work of the greater mechanism to which the volcanoes belong and the totality of the matter transferred from the earth's interior to its exterior, the lessons in land and continent making, and the conflict between the constructive work of the volcanoes and the destructive work of the atmosphere and ocean, one can not but consider the human events of the recent eruptions as indeed a trivial incident of the larger story. Here is a great amphitheater where the competitive battle of natural forces of construction and destruction have and are being fought—where vulcanism in its broadest sense is bringing up material from the earth to add to the land of its surface, to be attacked and redistributed by the exterior processes.

In fine, we have in these islands the spectacle of a battery of volcanic vents, pin-holes, in the ocean's bottom, leading up from the earth's interior, out of which for countless years the interior magma has been pouring its volumes of matter, adding material to the earth's crust, its atmosphere, and its oceans.

In view of the great stretches of history behind them and the relative insignificance of the seemingly large products of the recent eruptions of Pelé and Soufriere, we are also naturally led to doubt those explanations which have ascribed the recent eruptions to ephemeral and superficial causes, and to inquire if there is not a deeper-seated and more permanent source of vulcanism than many geologists have been prone to acknowledge.

Beyond the roar of the land-destroying ocean surf, in the unknown interior, beneath the veneering of the ash-made islands, in the great gas-sodden atmosphere above us, back of all the phenomena described, there is always presented for solution that still greater problem, What made the volcanoes?

Discussion as to Origin of the Volcanoes

DEDUCTIONS FROM THE WINDWARD VOLCANOES

The facts presented in the previous pages show that the recent eruptions of Pelé were not sudden nor produced by accidental superficial causes, such as the letting in of oceanic waters through fissures, but, on the other hand, they were a gradual emanation from an ancient, persistent deep-seated volcanic center which has existed beneath the vicinity since remote geologic periods.

The facts have also shown that these volcanoes, from a world-making standpoint, are not destructive engines, but, on the other hand, are great constructive agents building islands in the sea, adding mass to the pre-existing lands and volume to the atmospheric waters.

Inasmuch as these facts do not accord with the current popular ideas of volcanoes or those in most text-books, we feel that this paper would not be complete without a résumé of current theories of vulcanism and the presentation and correlation of some recent and rather revolutionary views thereof, which have been presented by various eminent men of science.

These views, while not pretending finality, are at least much more in accordance with geological facts than many that have collectively appeared hitherto, and will explain more satisfactorily the events of the recent eruptions of Pelé than the theories which are more popular.

A volcano is the terminal exhaust pipe of a concealed underground mechanism. Our geological studies of volcanoes are limited to the cones and craters which represent the outer rims of the exhaust pipes of these mechanisms leading up from the unknown interior of the earth, and even these studies must be carried on at a respectable distance when the volcano is at work.*

The chief result of studies under such unfavorable conditions has been to ascertain that the vent holes discharge at the earth's surface nearly every known chemical element in various combinations and forms—solids, liquids, and gases. These materials in the condition in which they reach the surface—for they convey but little idea of the conditions within the interior from which they have evolved—represent exhausted and completed products of nature's workshop within.

The concentration of our studies on these erupted products, together with the security in which we inhabit the earth's surface, has led many to regard the world as a completed or finished object, while in fact it is a living mechanism containing within itself forces and material capable of great chemical work like that so obvious in the sun and some other stellar bodies. Thus it is that purely geological studies of volcanoes have resulted chiefly in the presentation of numerous and confused systems of classification of the apparently infinite varieties of igneous rocks, which all students now admit to be but the varied manifestations of the one great material substance of the interior of the earth. It is at least discouraging to learn, after twenty-five years of collecting, slicing, and microscopically studying volcanic rocks, that petrographers have recently decreed that "there are no well defined chemical groups of rocks, but rather a continuous series with no natural divisions,"† thus admitting that the various forms of crystalline rocks as we see them in their cooled condition are but the differentiated products of a mother substance from which they have all evolved.

The geologist, notwithstanding all his studies of the earth's crust, its marvelous history and rearrangement of material, likewise admits that the great changes of level, such as the upheaving and subsidence of land and continents, are explicable by no known superficial agency, and realizes that there are planetary processes within the earth's interior beyond his power of solution. Geikie* confesses that

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*The field and laboratory geologists' opportunities for interpreting volcanic phenomena have many limitations. Their observation of the vital phenomena are as restricted as those of a man who endeavors to ascertain the great reactions which take place within a roaring furnace by distantly observing the escaping smoke from its cupola and studying the cold slag of its dump pile.

They can only see the superficial and relatively secondary phenomena of volcanoes—the top of the chimney—for nature has never exposed the deeper internal mechanism to view, or, at most, a shallow depth of what was formerly the underground portion of dead volcanoes, frequently exposed by erosion, showing a cast, so to speak, of some of the old rock material.

Traces may also be seen of what are called the "expiring after effects of vulcanism," such as dikes which push upward into the old cone or overburden as the cooling vents clogged, or deposits of copper, silver, gold, sulphur, and other metals which have either evolved from the great protomagma during the expiring after moments, and filled veins and fissures, or which were differentiated like the other elements of the rocks from the cooling magma into distinguishable ore segregations (pegmatitic) before being still further collected into more concentrated ore bodies by the subsequent circulation of atmospheric waters.

†Iddings, 1904.

> "not even a satisfactory solution of the problems of the upheavals and depressions of the land has been given. When we consider the wide tracts over which terrestrial movements are now taking place or have occurred in past times the explanation of them must manifestly be sought in some far more widespread and generally effective force in geological dynamics. The causes of upheaval and depression of land must again be traced back mainly to consequences of the internal heat of the earth."

Thus it is that the results of the purely geological study of the outer phenomena of vulcanism, the examination of volcanic craters and rocks, notwithstanding their long years of research and the great value from other points of view, so far as their contributions to knowledge of the conditions of the earth's interior are concerned, are incomplete and unsatisfactory, and science must turn to the physicist, the mathematician, and the astronomer for aid in investigating the earth's interior.

INADEQUATENESS OF CRUSTAL THEORIES IN EXPLAINING ERUPTIONS OF PELÉ

Owing to the fact that the geologist's observations are limited to the phenomena which he sees on the earth's surface, there has been a tendency to explain all the phenomena of vulcanism by the obvious exterior processes. These theories, with their multiplicity of variations, all try to associate volcanic phenomena with movements of the earth's crust, and some of them limit the causes and phenomena of vulcanism to a narrow zone of the earth's outer diameter. All hypotheses of this class may be grouped under the head of crustal theories.

The recent West Indian eruptions resulted in the attempted application of many of these crustal theories to the incidents in that region, and it was the writer's studies of the geology of the islands and the impossibility of fitting the facts to the theories that has led to the writing of this paper.

The various crustal theories differ in detail. The most popular and generally accepted of them is that volcanoes represent extrusions of gases and molten rock from the earth's subcrustal layers. Surface fissures are supposed to permit the entrance of surfical waters to the melted rock, creating an expansive force, which extrudes the material. Some advocates even maintain that the causes of the molten condition themselves are crustal, involving the melting of the rock through crustal movements.

Some maintain that the source of heat may be the load of the crust; others admit that it is the general heat of the earth, but require the inletting of surface waters to produce extrusion and explosion. Nearly all maintain that predetermined fissures are essential for volcanic extrusion and inletting of water, and all crustalists postulate that the water of eruptions is derived from crustal sources.

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* Text-book of Geology.

Mallet maintained that all the present manifestations of hypogene action are due directly to the more rapid contraction of the hotter internal mass of the earth and the consequent crushing in of the outer cooler shell. "The secular cooling of the globe," he remarked, "is always going on, though in a very slowly descending ratio. Contraction is therefore constantly providing a store of energy to be expanded in crushing parts of the crust, and through that providing for the volcanic heat." Professor N. S. Shaler has also advanced a crustal "blanketing theory," in which he accounts for the volcanic heat by continuous accretions of sediments or load.

The theory of the "fissurists," who maintain that volcanic action itself is due to the letting in of water through fissures to the hot magma, has been expressed by Dana, who states:*

> "For expansive eruptions, water in large quantities must gain sudden access to the interior of a magma conduit, for the projectile force of the abruptly generated vapors is enormous."

Russell,† in his excellent work on North American volcanoes, while admitting that the initial expansion of the magma forced it up into the subterranean fissures of the crust, postulated that the actual eruptions at the surface required the inletting of surface waters.

An exposition of the crustal theory, in its extreme development and application to the West Indian eruption, was recently set forth by Professor Milne in the Journal of the Royal Geographical Society of London for January, 1903.

Briefly stated, Milne's theory is that dormant volcanoes in a state of volcanic strain may be brought into activity by a mass displacement of a fold from which they rise. This displacement may occur a thousand miles or more from the site of the volcano. For instance, he alleges that the eruption of mont Pelé in 1851 was preceded by a great earthquake in Chile, fully 2,000 miles distant.

According to this author (but not so in nature), nearly all active volcanoes occur along the ridges of rock folds which are in proximity to oceanic waters. By the percolation of this water to the foundations of these folds, where it comes in contact with a heated magma, extraordinary pressures are developed, the sudden relief of which results in a volcanic outburst.

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*The term "magma" is used by geologists for the molten igneous volcanic fluid which differentiates into various kinds and forms of crystalline rock under physical conditions of pressure, cooling, etcetera.

†I. C. Russell: Volcanoes of North America, p. 308.

> . . . "A good illustration of this relationship between sudden movements of rock folds and displays of volcanic activity is to be found in the history of the volcanic eruptions in the West Indies and the large earthquakes which have occurred in the West Indies or in adjacent countries. As soon as a fracture occurs pressure is relieved, the deep hot rocks become fluid and are forced up the fissures by the weight of the crust."

Unfortunately for this theory, there is absolutely no indorsement in nature to its basic proposition that "nearly all active volcanoes occur along the ridges or rock folds which are in the vicinity of ocean waters."

In this connection it is interesting to note that M. de Montessus de Ballare,* from careful field studies reaches a conclusion opposite to those of Milne. He says:

> "It is very remarkable that the distribution of seismic instability in all degrees of intensity presented, in all possible combinations with the presence or absence of volcanoes, in their activity or their extinction, affirms at once a most complete independence in time and space of the two orders of phenomena."

The fissure theory has also been directly applied to Pelé by Jaggar † as follows:

> "A slip of some sort liberated a steam column; the cause of the fracture or the source of the steam is one step too far back into the theory to venture to treat it here. Release once started followed old vents, water holes, and these vents were Soufriere and Pelé. The explosion that followed release of pressure tore away the walls of the fissure and its violence ground the material to powder. The material came from a depth where the rocks were hot, and it was heated further by friction."

INTERIOR THEORY OF VULCANISM

Recent views on the condition of the earth's interior.—Of late years broader thinkers have realized more and more that the problems of the earth's interior could not be interpreted merely by geological study of its surface conditions, and that they required the assistance of the laws of chemistry, physics, and mathematics, by which we obtain our knowledge of the sun and other kindred heavenly bodies, of which our planet is one.‡ Great physicists, like Sir William Thompson, now Lord Kelvin; George Darwin, Newcomb, and others, by mathematical processes gradually destroyed the earlier hypotheses concerning a fluid condition of the earth's interior. As a result, and opposed to the crustal theories of origin of volcanoes,* these new ideas are focusing around the belief that volcanoes and their products are manifestations of forces and material existing within the interior of the earth itself, held by some to be neither liquid nor solid, but gaseous, and which by expansion has the power to ascend through the earth's crust and to produce by differentiation under different physical conditions of pressure and cooling all the known substances accompanying volcanic phenomena—rocks, metals, gases, and water.

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* Investigations on the earthquakes in the region of the equatorial Andes. Academie des Sciences, January 11, 1904.

† T. A. Jaggar: Popular Science Monthly, August, 1902, vol. lxi, p. 365.

‡ Major J. W. Powell, while Director of the United States Geological Survey, saw the importance of physical research in connection with the interpretation of the earth's interior, and at one time secured from Congress an appropriation to conduct experiments with high-pressure temperatures under the direction of Dr Carl Barus, now professor of physics at Brown University, but the investigation was too deep and far reaching for the appropriation committee to apprehend. The little work that Professor Barus did, however, before his allotment was expended remains as practically the only American attempt to rationally study the condition of the earth's interior.

These theories have recently been strengthened by four distinct lines of research, to wit, physical studies bearing upon the conditions of the earth's interior; practical researches in deep mines by various eminent geologists in relations to the origin of ore deposits; Professor Suess' conclusions as to the interior origin of atmospheric waters; Sir William Ramsey's investigation of gases exhaled by the earth. The writer's own personal unpublished investigations of the geologic history of the West Indian and Central American and Mexican volcanoes have at least led him to believe that the interior theories are much nearer the true explanation of vulcanism than those of the crustalists.

In America interest as to the nature of the earth's interior has been principally kept alive by a practical, rather than the merely theoretical, line of research. Mining methods have advanced beyond the old axiom of "follow the ore" to the scientific stage where the modern miner employs geologists to explain and "hunt the ore" by studying laws of origin and occurrence of mineral deposits. The widespread scientific study of the origin of ore deposits has resulted in views concerning the earth's interior far in advance of those maintained by the purely academic geologist. Men like Kemp, Lindgren, Weed, familiar with deep mines as well as theoretical geology, whose researches the writer could largely supplement by his personal observations of the great mines, realized the intimate relation of metallic ore bodies to the great interior processes of the earth.

Arrhenius' theory of a gaseous center.—In a volume published by the Institute of Mining Engineers on the subject of ore deposits a few years ago Vogt † quoted some paragraphs from the writings of Professor Arrhenius, the eminent Swedish physicist, who presented for the first time in this country an intelligible hypothesis of the conditions of the earth's interior and its contributions to the crust, which alike satisfied the requirements of the mathematical physicists and explained far better, at least, than the heretofore superficial phenomena of vulcanism.

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* Even the crustalists like Dana admit that "igneous action has its origin almost exclusively within the earth's interior," p. 556, while it is generally acknowledged that deep-seated rocks on account of their high temperature are in a potentially plastic or even gaseous condition, which may become plastic on the relief of pressure.

† Transactions American Institute of Mining Engineers, vol. 18.

Professor Arrhenius' conclusions thus cited were that the crust of the earth is solid to a depth of about 40 kilometers where there is a temperature of about 1,200 degrees centigrade and the pressure of about 10,840 atmospheres—that is to say, at this depth begins a liquid molten condition. Beyond that, 300 kilometers, the temperature must, without doubt, exceed the critical temperature of all known substances, and at this point the liquid magma passes gradually to a gaseous magma subject to extremely high pressure. The viscosity and lack of compressibility may be greater than those of the liquid magma. These liquids and gases possess a viscosity and incompressibility such as to permit them to be regarded as solid bodies.* This great interior, which is the foundation of Arrhenius' theories, with its celestial temperatures, and which its author considers as gaseous, is explained as being "something wholly different from what we ordinarily understand as gases."†

By experiment and deduction we know that all the rocks of the earth's crust can be melted into liquids and at still higher temperatures converted into gases. It is also known that hot gases can cool into molten liquids, which in turn change into solids on further cooling. It is not illogical to suppose that these processes are repeated, and that from a greater and more primitive gaseous protomagma, as postulated by Arrhenius, all the material of the earth's crust, which is all secondary matter, with its variety of forms and conditions, have been evolved.

Granting that matter in the earth's interior does exist in a gaseous or potentially gaseous condition, and remembering that these gases are composed of all known elements of the earth's substances, the mind can also conceive that on escaping to the cooler surface these gases as they approach the outer crust and atmosphere will be gradually and successively converted into all known primary forms of minerals, water, and gases as they exist on the crust today, first condensing into liquids and then into solids, producing exactly the conditions seen in the workings of a volcano, which, as deeply as we can see into it or its roots as exposed by erosion, is merely the cooling superficial crustal terminus or conduit of a cooling gas column leading from the greater invisible depths to the surface.

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* "Zur Physik des Vulcanismus." Geol. Foren i Stockholm Forhandl., xxii (1900), pp. 395–419.

† At this point we may be pardoned for suggesting a new term which will assist in the discussion of the interior theory. In Arrhenius' statement it will be noticed that he recognizes three zones of condition—the outer crust, the molten inner layers, and the great gaseous centrum. The term "crust" is an accepted one. The liquid mass is the magma. For the matter of the great interior centrum from which the liquid magma and all the known substances and the superfice have theoretically differentiated no name is given. For the want of a better term this great protoplasm of the inorganic world might be called "protomagma."

This gaseous theory of Arrhenius, so revolutionary to previous conceptions of the earth's interior, and which hitherto has been recognized in America only by the students of mining geology, has lately received the approval of Sir Archibald Geikie. This recognized leader of geological thought, in the newest edition of his "Text-book of Geology," 1903, received while the present paper is being written, generously states that

> "For some of the latest views regarding the nature and origin of volcanic action we are indebted to Professor Arrhenius, of Stockholm, whose observations on the probable condition of the earth's interior have been already cited, and who, bringing the results of modern physical and chemical research to a consideration of the subject, confirms what has been the growing belief on the part of geologists in regard to this part of their science. . . . The aspect thus presented of the probable constitution of the interior of our planet appears to accord well with the geological requirements. Not only does it furnish an explanation of the characteristics of earthquake movements, but, as Professer Arrhenius cogently shows, it helps us to understand some of the more difficult problems of volcanic action."

Thus Arrhenius gives science the first tangible hypothesis with which to combat the assertion of the crustalists that the heat and materials of vulcanism are generated within the subcutaneous layers of the earth by crustal load and movements. We can now see that within the earth's centrum is contained matter so intensely hot that its temperature may be classed as celestial. This matter contains all the elements of the crust metals, gases, and rocks; possesses the potentiality to escape from the interior through the crust to the surface, and the power to assume an infinite variety of forms, combinations, and conditions as it approaches and reaches the surface.

Source of the water of vulcanism.—While Arrhenius' theory has given us a more reasonable working hypothesis than any hitherto possessed concerning the interior, the source of water of vulcanism still remained the bone of contention. The crustalist views largely centered around the belief that the water of volcanoes is superficial and admitted to the magma from above, thereby creating the steam of expansion and explosion.

Thoughtful investigators have also lately been finding many reasons for disbelieving that the inletting waters of the oceans have been the exciting cause of vulcanism, and have boldly suggested that the water of volcanoes, instead of being contributed by the oceans, is derived from the gases of the earth's interior. They have even inquired if the oceans—the great aqueous envelope of the globe—have not been made by contributions from the condensation of volcanic gases from its great cooling, shrinking interior protomagma.

An objection long since pointed out by Geikie to "the constant influx of water from the surface is the difficulty of conceiving that water should descend at all against the expansive force within. Experience in deep mines, however, rather goes to show that the permeation of water through pores of rocks gets feeble as we descend."

Still another argument against the water of vulcanism being derived from the surface has been the fact that the volcanic rocks were largely composed of water-making gases, which entered into combinations far below the surface and under conditions of temperature where surface water could not exist.

It is well known that the crystals of deep-seated igneous rocks contain gas and liquid-filled cavities, due to the presence of gas or steam in the crystal at the time of consolidation. The usual gas is hydrogen, with traces of oxygen and carbon-dioxide. Sometimes it is entirely carbon-dioxide or hydrogen and hydrocarbons; the liquid cavities are usually filled with water in which carbon-dioxide may be present. In most of these cases the liquid inclusions are to be referred to the conditions in which the mineral crystallized out of the original magma.

The fact that granite, a deep-seated magma, when heated to 1,000 degrees centigrade was found by Gautier to give off more than 20 times its own volume of gases and 89 times its volume of steam as vapors shows that under the conditions of original solidification these gases were present in the deep-seated interior.

Professor Kemp quotes him as follows:

> "If we give due weight to the expansive power which these rock gases must develop whenever the pressure upon the heated rock in the interior of the earth permits, we see that the old theory of the production of volcanic outbreaks by the introduction of water is no longer necessary. By a still stronger ignition the volume of the emitted gases appreciably increases. . . . When one realizes the explosive power which this implies, one may dismiss the introduction of surface waters into the glowing reservoirs of rock from the theories of volcanic action." *
>
> "The abundant occlusion of hydrogen in meteorites and the capacity of many terrestrial substances, notably melted metals, to absorb large quantities of gases and vapors without chemical combination and to emit them on cooling with eruptive phenomena, not unlike those of volcanoes, have also led some observers to conclude that the gaseous ejections at volcanic vents are portions of the original constitution of the magma of the globe, and that to their escape the activity of volcanic vents is due."

Thinkers who took the view that the water as well as the rocks were protomagmatic did not make much impression against the crustal vulcanologists, however (judging by the way in which crustalists continued to pour in the ocean into the roots of the recently active West Indian volcanoes). until recently when they found a new champion in Professor Suess, of Vienna, who, with Geikie, stands preeminent among the world's greatest geologists.

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* Zeitschrift fur Practische Geologie, October, 1901, p. 303; cited by J. F. Kemp, Trans. Amer. Inst. M. E., October, 1903.

Breaking away from the old traditions, this eminent leader of geological thought during the past year has boldly advocated that the sources of the waters of hot springs and volcanoes are internal and not superficial, and that the waters of these are distinct contributions from the earth's interior to its exterior. He says:*

> "The steam of the volcano cannot be derived from surface infiltration; for, if it is, whence the carbonic acid? Both must come from the deeper regions of the earth; they are the outward sign of the process of giving off gases which began when the earth first solidified, and which, today, although restricted to certain points and lines, has not yet come to a final end. It is in this manner that the oceans and the whole surface hydrosphere have been separated from the solid crust. Volcanoes are not fed by infiltration of the sea, but the waters of the sea are increased by every eruption."

THEORY OF LINEAR ARRANGEMENT ALONG FISSURE LINES

Another position of the crustal theorists has been the assertions as to the linear arrangement of volcanoes along certain great lines of imaginary fissures in proximity to the sea, the actual known occurrence of some volcanoes along fissures, and the presumption that the volcanoes could not have within themselves the power to reach the surface without the preexistence of these fissures through which the water was let in.

It is now found that even the data on which these deductions are based are not conclusive. Volcanoes do and have occurred both on the land far away from the sea and in the sea far away from the land. So far as the occurrence of volcanoes adjacent to the ocean margin is concerned, it may justly be argued that this arrangement is in part the natural sequence of occurrence along lines of least resistance and partially due to the fact that these marginal land volcanoes are merely the fringe of the greater area of marine volcanoes concealed by the ocean. Indeed, increasing evidence is accumulating that the greater number of volcanoes, past and present, are marine and not accompaniments of the land areas, but really makers of the land areas, the continental interiors representing areas where in times past the crust has already been so thickened by volcanic extrusions as to prevent egress of volcanic gases in those localities.†

While admitting that volcanic protrusions naturally may follow preexisting lines of weakness, such as faults and fissures, the fissuring also usually follows the volcano. Instances are even found in the San Francisco and Mount Taylor regions of volcanoes far distant from oceanic waters without a trace of preexisting fissures where the magma has forced itself up through thousands of feet of sedimentaries.

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*Professor Eduard Suess, Royal Geographical Journal, vol. xx, November, 1902, p. 520.

†In this connection see the excellent chapter on submarine volcanoes in the new edition of Geikie, vol. i, pp. 332-342, and his proof of the conclusion that "volcanic activity is displayed over a wider region of the ocean's floor than on the surface of the land and on a more gigantic scale."

In 1897 Geikie showed that the volcanic rocks of central Scotland "had been blown out without any trace of their coincidence with lines of fault." Bronco, in Schwabia, and Boese, in Mexico, have shown similar conditions. As we write these lines we read* that the sedimentary rocks through which the remarkable row of 19 old volcanic necks penetrate on the cape of Good Hope "never show the least shattering or plication."

It is much more reasonable to assume now that volcanic forces have within themselves the power to penetrate to the surface. If the interior of the globe, as Arrhenius and other physicists hold and as cited by Vogt,† is vast masses of highly superheated and compressed gases, these gases must ever be seeking release through any porosity or even by their own solvent powers. Ascending through the subcrust either from long cooling and condensation, the contact with the vadose circulation may have converted into ascending springs, the hot water of which possesses the powers of solution and erosion sufficient to create a vent. To assume that the conditions of the highly heated interior of the earth are important is by no means a secure conclusion.

THE MAGMATIC HYPOTHESIS

The magmatic hypothesis not only conforms more nearly with our geological facts than the crustal, but with the greater astronomical history of our globe, which, when considered, invariably leads back to the hypothesis that the earth at one time in its astronomic history was an undifferentiated magma of hot gases, like the sun. The present interior of the earth, as a sequence of its history as a cooling globe, must still inherit some of its ancestral conditions and all of the present materials of the crust must be the ultimate products of a great mother magma, the remnant of which, outwardly encrusted, still constitutes the interior, with inherited celestial temperatures.

Since the year 1900 there have been important additional contributions from separate lines of research, which collectively give courage to those who have never been able to accept the crustal theories. These contributions all tend to uphold the theory that the interior of our globe is a living field of potential activity, from which matter is constantly forcing its way in a gaseous state through the outer crust, ocean and atmosphere. In fact, the dead-planet view dissolves on considering some of these great processes going on within, and there is far more reason to believe that it is still a live, heated mechanism, containing beneath the outer crust or shell a great interior magma, with all the mighty forces and activities of uncombined chemical elements.

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* Report Geological Commission, Cape of Good Hope, 1900–'02.

† Zur Physik des Vulkanismus (Geol. Foren. Forh.), Stockholm, 1900.

Evidence is rapidly accumulating that the earth is constantly exuding its interior substance as gases into space, and that its interior is a great reservoir of material and forces from which invisible matter is escaping. Sir William Ramsey has just announced that the supply of helium, an element only recently discovered by Raleigh in the atmosphere and which is known to exist in the sun, is constantly passing from the earth to the atmosphere. It not only comes up with the hot springs, but presumably oozes from the soil, and the quantity thus escaping is from 3,000 to 6,000 times more than can be accounted for as a return to the atmosphere of helium washed down by rain.

In the light of the interior theory, vulcanism in its simplest conception may be theoretically considered as the transfer of matter from the earth's interior to its exterior in the proportion of about 1 part of solids to the crust and 99 parts of gases to the atmosphere and ocean. The enormous masses of crystalline rocks now found on or near the surface of the earth (and we have no language to express its weight in tons or dimensions in cubic feet) represent secondary material differentiated from the interior gaseous protomagma. These rock masses which now appear to us as solids may be merely gases which have been locked into conditions of stability by chemical and physical combinations.

Reduced to the simplest statement, the interior hypothesis of volcanoes is that they are gas vents, and volcanic rocks are their by-products.

In view of the facts presented, may we not weigh with consideration the words of the venerable Professor Suess, of Vienna, one of the world's greatest geological thinkers, who has lately stated that

> "volcanoes are not fed by the infiltration of ocean water, but ocean water received additions to its volume by every (volcanic) eruption. . . . The hottest dry fumaroles, forming deposits of the ore by sublimation, the rain of hydrochloric acid from Vesuvius and the salt of the Altenzalza mines, the hot vapors which recently burned the bodies of the unfortunate victims at Martinique without setting fire to their clothes, and the warm, healing waters which rise up here before our eyes are members of one individual series of phenomena. The earth is still giving off gases in a manner which may be compared to what we observe in the spots on the sun or on every large mass of cooling steel."*

The traditions of geology have held the majority of its students to the crustal theories, but beyond the rank and file there are a few larger minds who see greater causes than the simple testimony of the cold, dead crust. These constitute the nucleus of the modern school of geology, which, with the aid of the physicist, the chemist, and the mathematical astronomer, will ultimately solve the great problem of the physical nature of the basic primitive matter of the earth's interior, from which all known crustal substances have been evolved through volcanic action.

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* E. Suess: Hot springs and volcanic phenomena. The Geog. Jour., London, vol. xx, 1902, p. 522.

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PIEDMONT DISTRICT OF PENNSYLVANIA*

BY F. BASCOM

(Read before the Society December 30, 1904)

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GEOGRAPHY OF THE PIEDMONT

GENERAL RELATIONS

Of the three physiographic provinces into which the Atlantic border region is divisible—the Appalachian district, the Piedmont plateau, and the Coastal plain—the Piedmont plateau preserves the record of the longest and most varied geologic and physiographic history.

The plateau lies at the southeastern foot of the Appalachian system and is separated from the Atlantic ocean by a belt of coastal plain of variable width and from the edge of the continental plateau by a belt of coastal province possessing a uniform width of 200 miles.

The Piedmont district extends north and south from Maine to Alabama, with an average width of 50 miles. Its western limit is defined by the eastern slopes of the Blue ridge; its eastern boundary is defined by an equally conspicuous change in topography, the abrupt transition from a diversified upland to an undiversified lowland.

Eastward from this boundary the navigable streams, opening into tidal estuaries, afford good shipping facilities. Westward the streams cease to be navigable and occupy rocky channels. At the head of navigation and on the boundary between plateau and plain are situated many of the large cities of the Atlantic states.

In general the plateau is a level upland of moderate elevation, sloping east and southeast, with shallow valleys and scattered residual eminences. South of the New England states these eminences do not rise above a height of 1,600 feet, while the plateau varies from 200 feet in the east to 1,200 feet on its western edge. The level lines of the plateau are unrelated to the underlying rock structure. The larger streams, which have cut into the plateau, converting it into a diversified upland, have maintained courses which are independent of the structure and character of the rock floor. The tributary or subsequent streams, on the other hand, are adjusted to the rock floor, and by means of them the heterogeneity of rock constitution and complexity of rock structure is finding expression.

The upland is covered by a thick mantle of fertile soil, comparatively free from stones and exposing few rock ledges.

LOCAL RELATIONS

The Piedmont district of Pennsylvania, forming with a width of 65 miles the southeast portion of the state, is an important part of the Atlantic Piedmont. In geology and physiography it is an epitome of the larger district.

Geologically the Piedmont district is a complex of highly metamorphosed sedimentary and intrusive igneous materials of pre-Paleozoic and Paleozoic age largely concealed beneath a cover of unmetamorphosed sandstones and shales and unconsolidated gravels, clays, sands, and marls of Mesozoic and Cenozoic age. The pre-Paleozoic and Paleozoic crystallines are exposed on the southeastern and northwestern borders of the Piedmont district and are covered in the central portion of the region by the Triassic sandstone and shale series.

It is the purpose of this paper to discuss the formations and structures of the southeastern exposure of crystallines.

This belt trends northeast and southwest, with a width, in the region of Philadelphia, of 20 miles. It widens southwestward and pinches out northeastward, where it disappears under a cover of Triassic, Cretaceous, Tertiary, and Quaternary material and emerges again at the surface in northeastern New Jersey, southeastern New York, and in New England.

The valley of the Delaware is the southeast boundary of this belt. From this valley, which is less than 20 feet above sealevel, the upland gradually rises, reaching, at a height of 160 to 180 feet, the base of a well defined escarpment. This escarpment, which is marked by the 180 and 200 foot contour lines, extends from Somerton on the northeast southwestward to Gordon heights. Fox Chase summit, Green Lane reservoir, Swarthmore College buildings, and the Chester reservoir are located on its crest, from which the relatively flat slope to the Delaware can be surveyed.

Northwest of the escarpment a more rugged topography prevails. The upland rises more rapidly, and 10 to 14 miles northwest of the Delaware elevations of 400, 460, and 500 feet are reached. These elevations mark the level tops of hills, which trend northeast and southwest, and which constitute a more or less well defined topographic feature known as Buck ridge.

In the central portion of the belt Buck ridge is separated by a shallow valley ("Cream valley") from well.defined hills rising to a height, at Paoli and Devon, of 520 feet. These hills are known as the south Chester Valley hills.

Beyond them lie Chester valley, with a width of 2 miles, and the north Chester Valley hills, also trending northeast and southwest and rising to a height of 600 feet. The contours of these hills and of Chester valley are controlled by the underlying Paleozoic formations.

To the northward these materials pass under a cover of Triassic shales.

In the northeast Buck ridge and the south Chester Valley hills are merged; Chester valley is first reduced in width and then disappears and Buck ridge itself passes under the Triassic cover.

With the presence of the Trias there appears a marked change in topography; the marked northeast-southwest trend of ridge and valley disappears; well defined ridges do not exist and the range of elevation decreases. The more open, level character of the district underlain by Triassic formations is conspicuous from the summit of the north Chester Valley hills, which separate the country of the Paleozoics from that of the Triassic formation and command both districts.

In the southwest the belt of pre-Paleozoic and Paleozoic materials widens, passing into Delaware and Maryland with a width of more than 80 miles and preserving the southwest trend of ridge and valley.

The south Chester Valley hills and Buck ridge again merge. Chester valley maintains its integrity until within 8 miles of the Susquehanna river, where the topography abruptly alters by reason of underlying harder formations coming to the surface.

GEOLOGY OF THE PIEDMONT

GENERAL GEOLOGY

In the Piedmont of western New England, Pumpelly, Dale, and Wolff* have determined the following succession:

Silurian: Berkshire schist.
Cambro-Silurian: Stockbridge limestone.
Cambrian: Vermont quartzite.
Pre-Cambrian: Stamford gneiss.

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* Monograph xxiii, U. S. Geol. Survey, p. 13.

For the Piedmont of southeastern New York, Merrill* gives the following succession:

Silurian: Hudson schist.
Cambro-Silurian: Stockbridge dolomite.
Cambrian: Poughquag quartzite.
Pre-Cambrian: Fordham gneiss.

In the Maryland Piedmont, Mathews † has determined the following series:

Silurian: Peach-bottom slates, Cardiff quartz conglomerate.
  Wissahickon mica-schist, including an upper phyllite member.
Cambro-Ordovician: Cockeysville marble.
Cambrian: Setters quartzite.
Pre-Cambrian: Baltimore gneiss.

In the District of Columbia, in Virginia, North Carolina, and Tennessee, Keith ‡ includes the mica-schist, mica-gneiss, and granite-gneiss under the division:

Pre-Cambrian or Archean Carolina gneiss.

The Pennsylvania Piedmont shows a similar series of arenaceous, calcareous, and argillaceous sediments.

SEDIMENTARY SERIES OF THE SOUTHEASTERN BELT

This belt contains the full series of sedimentary formations found to the westward in the Pennsylvania Piedmont. The original character and structures of these formations, however, have been rendered more obscure than is the case with the western belt by greater metamorphism, due both to dynamic forces and to the injection of great masses of acid and basic igneous materials.

The sedimentary series has been completely recrystallized and indurated; the argillaceous sediments have been converted into gneisses and schists; the arenaceous sediments into quartzite and quartz-schists; the calcareous material into marble.

The dynamic forces which have metamorphosed the sediments were generated by tangential thrust in southeast-northwest direction, which, combined with gravity, has also produced longitudinal folds, striking northeast, cleavage normal to the compressive force, and fissility both normal and diagonal to the force.

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* New York City Folio, no. 83, U. S. Geol. Survey.

† The American Journal of Science, vol. xvii, February, 1904, p. 143.

‡ The Washington Folio, no. 70, U. S. Geol. Survey.
The Asheville Folio, no. 116, U. S. Geol. Survey.

The igneous intrusives cut across the belts of sedimentary material more or less irregularly, but in general show a northeast-southwest trend.

The sedimentary series of the Piedmont complex fall into four groups:

Ordovician: Wissahickon mica-schist and mica-gneiss.
Cambro-Ordovician: Chester Valley limestone.
Cambrian: Chickies quartzite.
Pre-Cambrian: Baltimore gneiss.

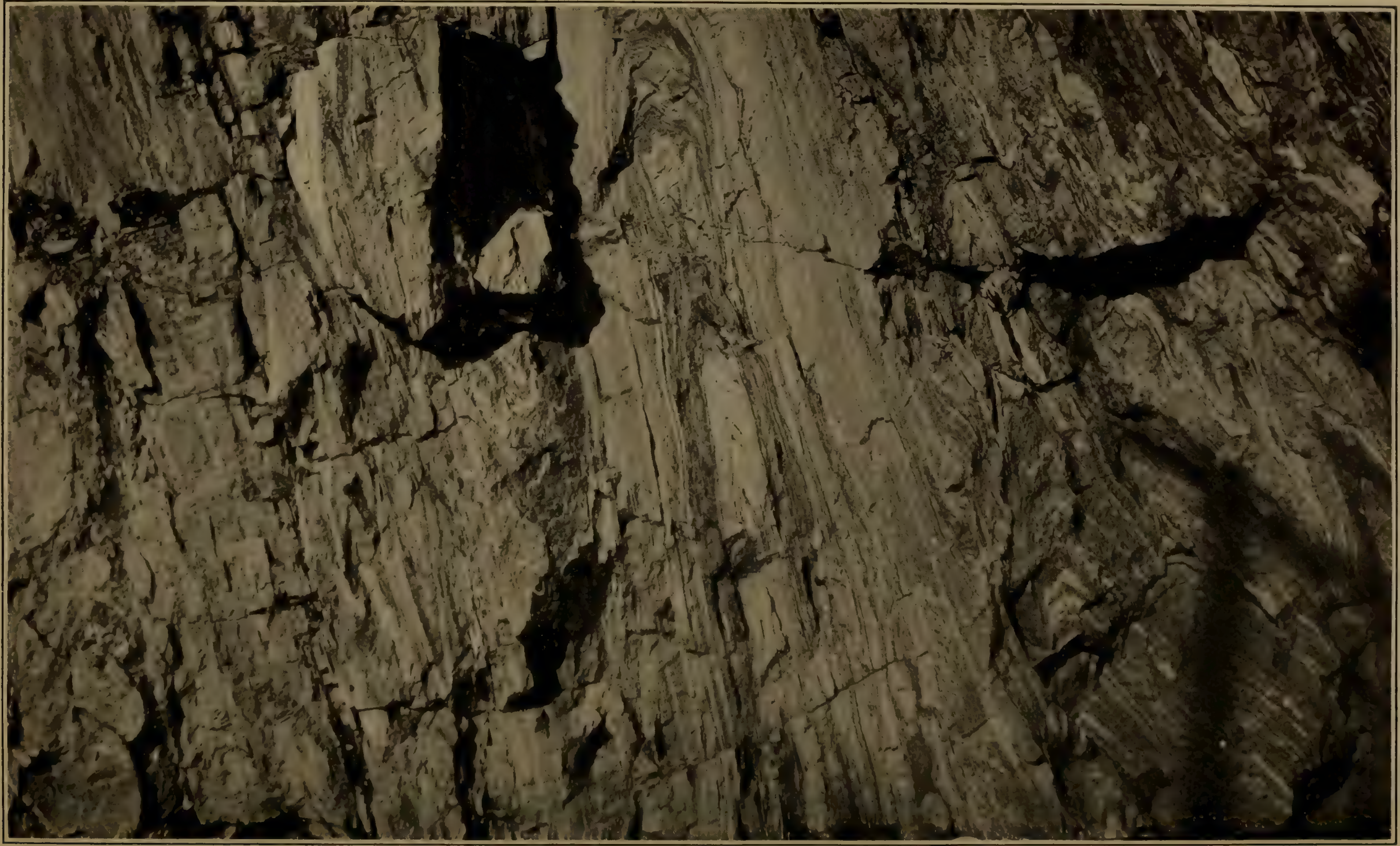
PRE-CAMBRIAN ROCKS: BALTIMORE GNEISS

Distribution.—This formation appears in the central portion of the belt and traverses it obliquely to the northeast. It is very thoroughly injected by gabbro, which, with the Baltimore gneiss, constitutes the flat-topped highland known as Buck ridge. North of Chestnut hill the gneiss belt becomes very narrow, though still persistent and expanding again to the northeast. It is bounded by faults throughout most of its extent. The formation is best exposed on the east bank of the Schuylkill between Lafayette and Spring Mills.

In Cecil county, Maryland, the Baltimore gneiss occurs in a narrow, wedge-shaped area (1 mile by 3½) on the Susquehanna river 2 miles northwest of Port Deposit. It expands southwestward in Harford county.

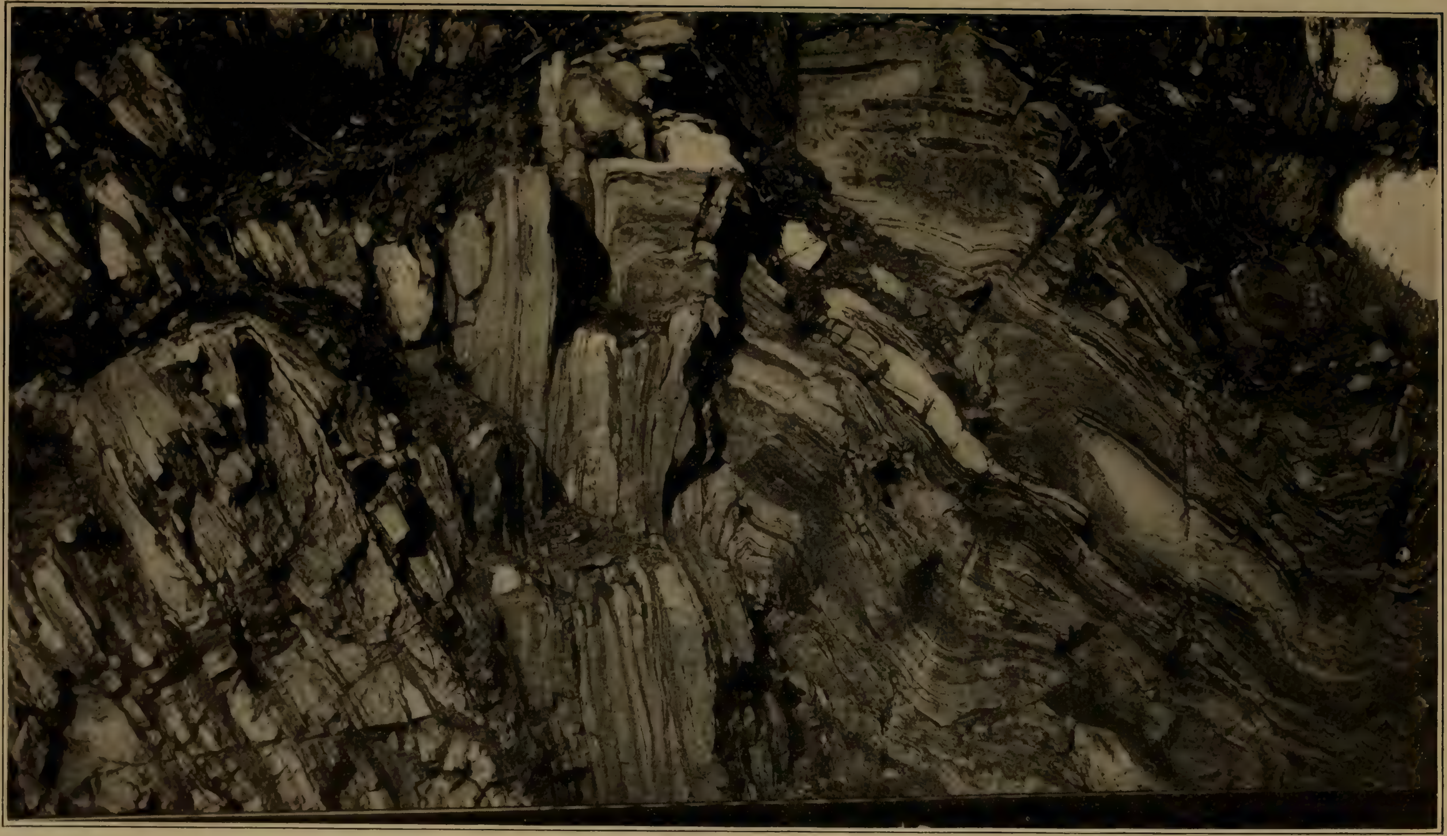
Character of the formation and stratigraphic relations.—The Baltimore gneiss is a medium grained, thoroughly crystalline aggregate of quartz, feldspar, and biotite, and is characterized by a pronounced banding, which may be very fine and intensely plicated. A gritty feel and a pseudo-porphyritic texture further characterize the formation. To the alternation of layers of biotite with quartz layers or quartz-feldspar layers is due the finely gneissic character of the rock. Biotite occurs in minute plates and is never developed in such dimensions or in such excess as to render the formation schistose. Associated with the biotitic layers are hornblende, epidote, titanite, garnets, and more rarely staurolite or augite. Hornblende is sometimes as prominent a constituent as biotite, and, like it, arranged in layers. Rounded apatites are also present. The feldspar is microline, orthoclase, and acid plagioclase of about the composition of oligoclase. The porphyritic texture is due to the presence of lenticular areas of quartz and of feldspar irregularly interspersed along layers. These lenses are without crystal boundary and distinctly pebble-like in character. They are sometimes a marked feature of the rock and indicate an original conglomeratic character.

The fresh character of the crystallization and absence of pressure effects on the crystals, indicating that strain was relieved by recrystallization, the rounded apatites, the quartz and feldspar pebbles, the sort-



CONTORTED BALTIMORE GNEISS

Schuylkill River section south of Spring mill, Montgomery county, Pennsylvania. Photographed by E. B. Harden



CONTORTED BALTIMORE GNEISS

Schuylkill River section south of Spring mill, Montgomery county, Pennsylvania. Photographed by E. B. Harden

ing of the mineral constituents, are microscopic evidences of an aqueous origin. In the field the gneiss has the appearance of a stratified formation. In the Schuylkill section the formation is heavily bedded and shows fan folding, with crumpling on the periphery (see plates 48 and 49). In the center the folds are gentle and open. The formation also contains considerable disseminated graphite, which has been mined in Montgomery and Chester counties. A chemical analysis of assorted samples of the formation shows an acid rock whose composition, as is to be expected in the case of assorted samples, is of a granitic character and not decisively that of a sediment. The two analyses, which represent each a single locality, more distinctly indicate the sedimentary character of the formation.

Chemical analyses of Baltimore gneiss

	I.		II.		III.
SiO_2	70.21		72.99		63.93
Al_2O_3	13.95		10.90		12.02
Fe_2O_3	1.05		0.55		2.40
FeO	3.08		2.50		2.95
MgO	1.26		1.07		2.44
CaO	3.10		1.88		4.00
Na_2O	3.27		3.34		3.15
K_2O	2.69		1.20		0.84
$H_2O +$	0.48		1.47		1.30
$H_2O -$	0.19				
CO_2	0.11	C	1.13		Not det.
TiO_2	0.52		0.84		1.04
ZrO_2	Trace.		....		.....
				Co_2	0.51
P_2O_5	0.10		0.18		Not det.
Cl	Not estimated.		....		.....
F	Not estimated.	FeS_2	1.61	Fe_7S_8	4.04
S	0.09		....		.....
NiO	Faint trace.		....		Trace.
MnO	0.11		....		Trace.
BaO	0.09		....	CuO	Trace.
SrO	Trace.		....		.....
Li_2O	None.		....		.....
	100.30		99.66		98.62

Analysis I was made by W. F. Hillebrand, of the United States Geological Survey, from six samples representing six localities.

Analyses II and III were made by F. A. Genth, Jr., volume C 6, Second Geological Survey of Pennsylvania, pp. 116, 105. Material of II was from Johnson's farm, 1 mile east of Feasterville and north of road to Somerton. Material of III was from west side of Neshaminy creek, on the property of Phineas Paxon.

In the neighborhood of the intrusive gabbro mass the Baltimore gneiss loses its stratified character and becomes massive and darker colored. The change in color is due to the development of hornblende, or more rarely augite, and of garnets, which develop in great profusion in the contact zone. The central body of gneiss is very completely penetrated by the gabbro. The banded structure is therefore much more conspicuous on the flanks of Buck ridge. A massive granitic character is considered an indication of the proximity of gabbro, although the gabbro may not always be exposed at the surface.

Thickness, correlation, and name.—There is no means of estimating the thickness of this formation, which is the floor upon which the other members of the sedimentary series were laid down. This gneiss underlies material known to be of Cambrian age and presumably Georgian. It is therefore pre-Cambrian and is correlated with the pre-Cambrian Stamford gneiss of western New England, with the Fordham gneiss of New York state, with the Baltimore gneiss of Maryland, and the Carolina gneiss of the District of Columbia and Virginia. While the pre-Cambrian gneiss of Pennsylvania is not stratigraphically continuous with the Baltimore gneiss of Maryland, similar stratigraphic relations, like lithologic character, and proximity of the two formations have found recognition in a common name. The pre-Cambrian gneiss of Maryland has been called the Baltimore gneiss because of a fine exposure of it on Jones falls, in the city of Baltimore. This name is also given to the pre-Cambrian gneiss of Pennsylvania. The Baltimore gneiss includes H. D. Rogers' "primal lower slate" and a part of his northern or "third gneiss belt." The major part of the "third gneiss belt" is gabbro. Both the Baltimore gneiss and the gabbro are included by the Second Geological Survey of Pennsylvania under the term "Laurentian gneiss."

CAMBRIAN ROCKS: CHICKIES QUARTZITE

Distribution.—This hard resistant formation constitutes the north Chester Valley hills, the highland at Hickorytown and Coldpoint, the hills west of Whitemarsh, Fort hill, Camp hill, the highland about Willow Grove, and the long ridge known as Edge hill and Lafayette hill; also the north Huntington Valley hills.

Character of the formation.—It possesses a conglomeratic lower member, which is largely composed of elongated pebbles of the blue quartz which characterizes the Baltimore gneiss. This member is brought to the surface in the nose of a pitching syncline. It may be found 1 mile south of Morganville and an equal distance east of Willow Grove. It is also brought to the surface on the middle limb of a fold at the base of the north Chester Valley hills, near the dam at Valley Forge. This conglomerate passes upward into a gray compact crystalline quartzite, which in turn grades into a silicious slate or into a sericitic quartz-schist, or is altogether replaced by the quartz-schist.

The sericitic quartz-schist is typically exposed in quarries one-half mile northeast of Somerton station and in the Edge Hill quarries. It is a thin bedded formation here. Bedding and cleavage coincide and dip steeply southeast. The quartz schist is of a light buff to white color and always contains feldspar. The feldspar is for the most part orthoclase, more rarely microcline, and is usually more or less kaolinized. Tourmaline, apatite, zircon, magnetite, and staurolite are accessory constituents. Stretched tourmalines are very characteristic of the formation. The schist readily cleaves into slabs and, by means of fissility developed in shear planes, into flattened rhombohedrons. Locally the quartzite may be quite geodiferous. The geodes are lined with quartz crystals. Quartzite of this character occurs at a locality known as "Diamond rock," on the southeast flank of the north Chester Valley hills. A chemical analysis shows the rock to be highly silicious, with sufficient alumina and potassa for sericite and lime-soda-feldspar. Analyses III and IV are of very sericitic facies of the quartz-schist.

Chemical analyses of Chickies quartzite

	I.	II.*	III.	IV.
SiO_2	87.87	84.59	58.97	56.35
Al_2O_3	6.61	....	22.61	22.28
Fe_2O_3	2.39	....	5.67	3.21
MgO	Trace.	....	0.25	1.40
CaO	0.24	....	0.08	0.19
Na_2O	0.19	0.19	0.32	0.38
K_2O	1.73	2.79	7.34	12.63
Ignition	1.20	1.66	3.73	2.89
TiO_2	0.38	....	1.11	0.82
P_2O_5	0.06	....	0.07	0.16
MnO	0.13	Faint trace.	....	Trace.
Li_2O	....	....	....	Strong reaction.
	100.80	....	100.15	100.31

I. "Itacolumite," 1½ miles southeast of Vanartsdalen's, near Neshaminy creek.

II. "Itacolumite," east bank Neshaminy creek.

III. "Itacolumite" from quarry northeast of Somerton.

IV. One-half mile south of Willow Grove station, Montgomery county, Pennsylvania. Analyses made by F. A. Genth, Jr., volume C 6, Second Geological Survey of Pennsylvania, pp. 107, 117, 121.

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* Partial analysis.

Stratigraphic relations.—The Chickies quartzite lies in an overturned synclinorium on the northwest flank of the Baltimore gneiss anticlinorium. It immediately overlies the Baltimore gneiss. There is no appearance of unconformity between the two formations, save as unconformity is indicated by the presence of the conglomerate member of the quartzite formation.

Thickness.—The thickness of the formation does not exceed and may be less than 1,300 feet, although the isoclinal folding gives the appearance of much greater thickness. Overturned folding with stratification and cleavage dips to the southeast are the prevailing structures. The average strike is north 50 to 70 degrees east and the dips 45 to 80 degrees southeast. Faulting explains the disappearance of the quartzite on the south limb of the anticline.

Correlation and name.—The name of the formation is taken from the locality of its finest exposure and greatest thickness on the Susquehanna river north of Columbia. At this locality *Scolithus linearis* has been found, which occurs also abundantly in the north Chester Valley hills, and the quartzite of this locality underlies quartzite in which olenellus fragments have been found by Mr Walcott,* thus fixing its age as Georgian or lower Cambrian. The quartzite of the southeastern belt, lying farther to the east than this typical exposure of Georgian quartzite on the Susquehanna river, may have been deposited in an encroaching sea, and thus represent a later horizon in the Cambrian than the Georgian. No forms of life save *Scolithus linearis* have been found in it; hence it can not positively be stated to be of Georgian age. It can safely be stated to be Cambrian, and is to be correlated with the Vermont quartzite of New England, the Poughquag quartzite of New York, and Setters quartzite of Maryland. It is the "primal sandstone" of H. D. Rogers and "formation number 1, Chickies sandstone," of the Second Geological Survey of Pennsylvania.

CAMBRO-ORDIVICIAN ROCKS: CHESTER VALLEY LIMESTONE

Distribution.—This is heavily bedded crystalline, white or blue magnesian limestone. Its surface exposure is largely confined to Chester valley, with a few scattered outcrops along the Huntington and Cream valley fault lines, and to the southeast in Chester county and Delaware. The presence of the limestone in Huntington valley along the course of Meadow brook is indicated by the character of the well water. The rock actually outcrops, however, only in the cellar of a wagon-house a quarter of a mile northeast of Meadow Brook station. In Cream valley,

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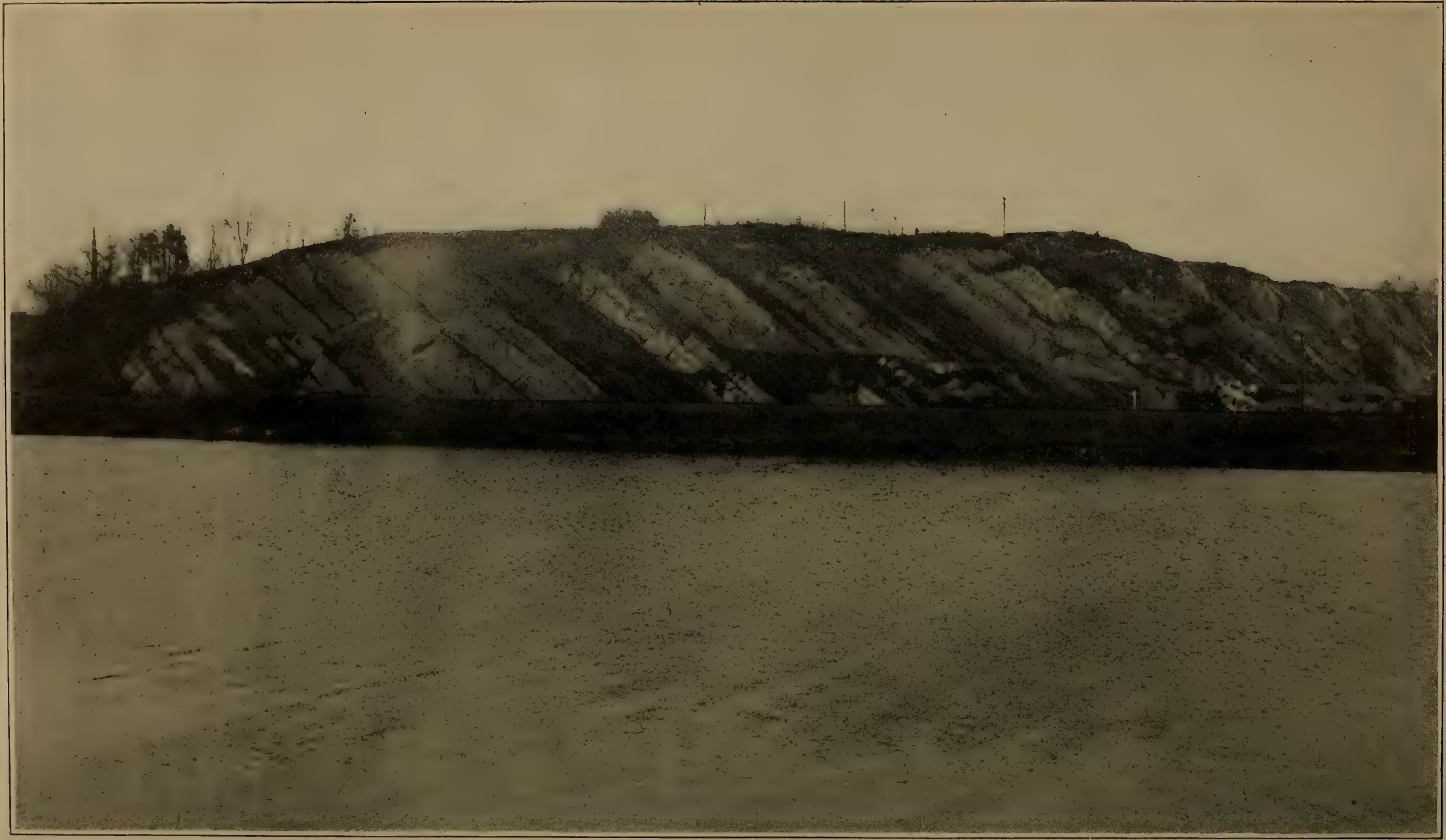
* C. D. Walcott: The Cambrian rocks of Pennsylvania. Bulletin U. S. Geol. Survey, no. 134, p. 17.



CHESTER VALLEY LIMESTONE

Showing uniform southeast dip. Schuylkill river, Montgomery county, Pennsylvania which lies on the west side of the Schuylkill and follows the southeast flank of the south Chester Valley hill, there are three exposures of the limestone—in West Conshohocken, at the head of the Gulf ravine, and in the bed of Gulf creek 1¼ miles southwest—while a series of sink holes in line with the strike of these outcrops attest the presence of the limestone near the surface. This line of outcrops is continued southwest in Chester county, where limestone comes to the surface at some seven localities and is farther exposed to the south of this series of outcrops at nine isolated localities.

Character of the formation.—The limestone is highly silicious and magnesian, but there are no analyses of it which give a sufficiently high percentage of magnesium carbonate to warrant calling the formation a dolomite.

Limestones from Mogeetown to Conshohocken

	1	2	3	4	5	6	7	8	9	10	11	12	13
$CaCO_3$	60.18	55.09	41.59	39.95	48.04	63.36	91.62	53.27	58.02	61.43	93.32	85.00	54.11
Fe_2CO_3	Not determined.			2.55	Not deter.		......	......	......	......	......	......	......
Insoluble residue	Not det.	2.59	26.48	46.10	37.60	2.65	7.85	9.83	5.89	6.60	5.63	4.79	3.15

West Conshohocken

$CaCO_3$	40.27
$MgCO_3$	31.24
SiO_2	24.23
Al_2O_3	1.12
Fe_2O_3	1.06
MgO	0.11
CaO	0.55
Alkalies	1.42
	100.00

Analyses made by F. A. Genth, volume C 6, Second Geological Survey of Pennsylvania, pp. 126, 127.

The limestone is always crystalline and increasingly so from west to east. Associated with increasing crystallinity is a lighter color, though blue and white marble may occur in the same quarry.

It is sometimes quite micaceous and is always so in the neighborhood of the overlying mica-schist. The beds immediately underlying the mica-schist are silicious, micaceous, and schistose, and are to be characterized as calcareous schist. It is abundantly traversed by calcite and quartz veins. Quartz, feldspar, phlogopite, graphite, pyrite, siderite, and limonite are accessory constituents.

Stratigraphic relations.—The limestone lies above the Cambrian quartzite in an overturned synclinorium. The prevailing strike is north 60 to

90 degrees east and the dips vary from 35 to 85 degrees southeast. There is a gradual change in the average strike and dips around the end of the synclinal trough in the northeastern end of Chester valley. As in the case of the quartzite on the limbs of the overturned isoclinal folds, stratification and cleavage dip are coincident when the stratification dip is to the southeast. The prevailing structure is isoclinal (see plate 50).

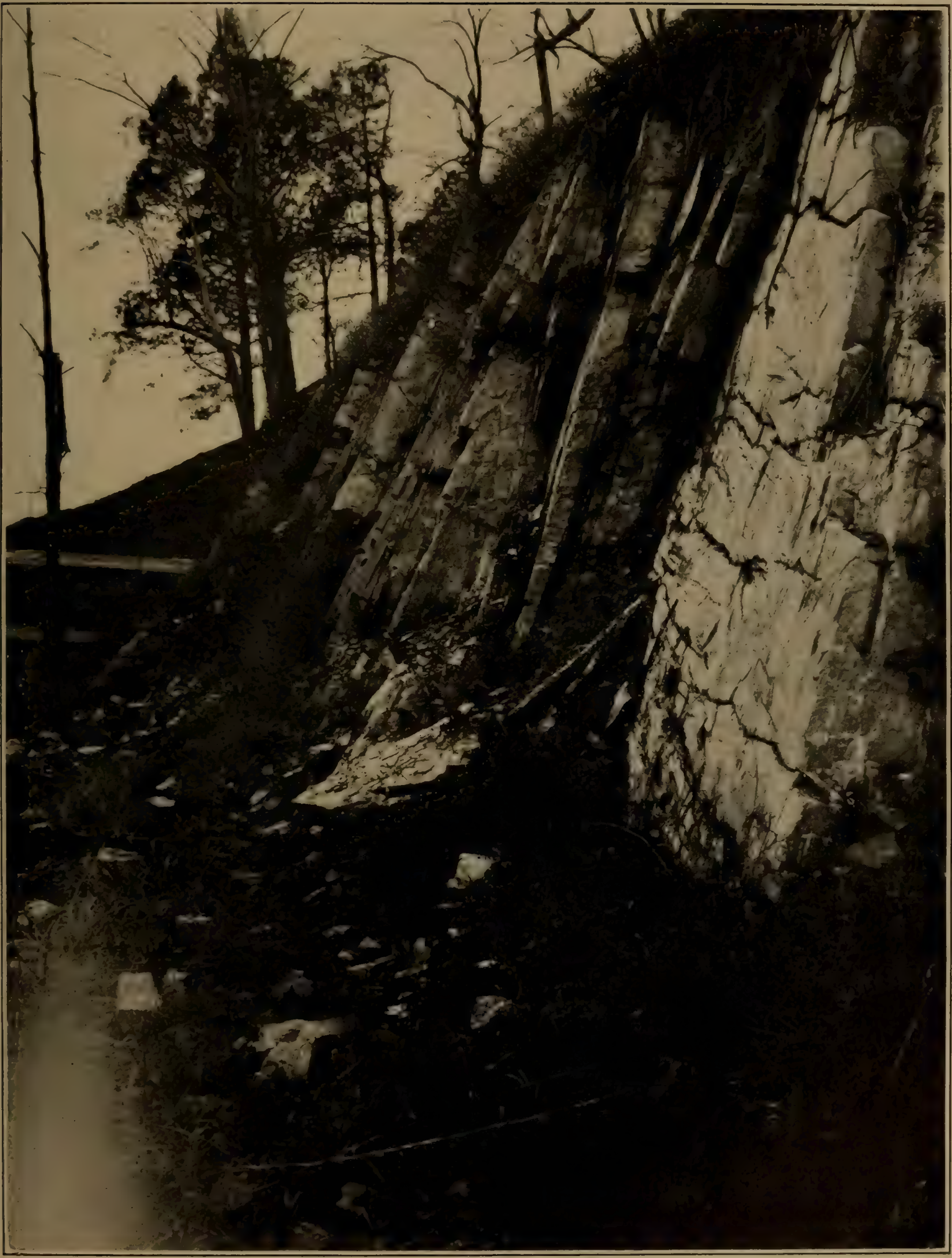
In an abandoned quarry at Rennyson, 1½ miles northeast of Berwyn, a compressed overturned syncline may be seen, with cleavage and bedding coincident and dipping steeply southeast on the limb of the syncline. An overturned isoclinal anticline is exposed in a rock cut on the north bank of Valley creek one-half mile north of Howellville (see plate 51). A similar overturned anticline is to be seen in the cut made by the Washington branch of the Pennsylvania railroad near Arlingham, 1½ miles southeast of Fort Washington. These secondary folds illustrate the type of the primary folding of the limestone.

The limestone of Cream valley and the limestone appearing in scattered exposures to the southwest, are brought to the surface by means of erosion on the crest of low anticlines, or fill the troughs of overturned synclines.

Thickness.—With the interpretation of the structure given above, the thickness of the formation must be much less than the width of its outcrop. It is not perfectly determinable, but probably is not greater than 1,500 feet.

Correlation and name.—Fossils of the Chazy, Calciferous, and Trenton ages have been found in the limestone occurring to the west of Chester valley and stratigraphically continuous with the Chester Valley limestone. Fossils have also been found in Chester valley in somewhat ambiguous material. This material is a geodiferous drusy quartzite, which is found in place south of Bridgeport near the Trenton branch of the Philadelphia railway, and which follows the contact of the mica-schist and the limestone, showing as loose boulders on the surface of the ground. It is interpreted as a secondary replacement of the uppermost calcareous beds of the Chester Valley limestone.

At Henderson station loose material of this character lies on top of the limestone, and in this material have been found gastropod and cephalopod fossils. The following determinations have been made: Raphistoma, two species; Maclurea, Lituites, and Cyrtoceras. These are Ordovician forms, and indicate a horizon in the upper half of the Canadian series. The limestone overlies conformably Cambrian quartzite and is Cambro-Ordovician in age. It is correlated with the Stockbridge limestone of New England and New York, with the Cockeysville limestone of Maryland, and the Knox dolomite of Virginia.



COMPRESSED ANTICLINE IN CHESTER VALLEY LIMESTONE

Chester valley, Chester county, Pennsylvania

It is part of the great Shenandoah belt of limestone, the "Auroral limestone" of H. D. Rogers, and "formation number II" of the Second Geological Survey of Pennsylvania.

Aside from a few scattered and minor exposures, the limestone of the southeastern belt is confined to and controls the form of Chester valley, a conspicuous topographic feature of this district. For this reason it has long been locally known as the Chester Valley limestone. This name is retained for the formation.

ORDOVICIAN ROCKS: WISSAHICKON MICA-GNEISS (MICA-SCHIST AND MICA-GNEISS)

Areal distribution.—The formation overlying the Cambro-Ordovician limestone occurs in two areas, separated by the Buck Ridge complex of pre-Cambrian gneiss and gabbro. One area lies to the northwest and the other to the southeast of Buck ridge.

The lithologic character of the formation differs somewhat in the two areas. In the northwest it is characteristically a mica-schist and in the southeast a mica-gneiss.

Distribution of mica-schist.—The mica-schist is chiefly confined to the south Chester Valley hills, expanding to the southwest, where the hills cease to be a distinct topographic feature and where Buck ridge pitches under the mica-schist and mica-gneiss, which here graduate into each other. Outliers of the mica-schist occur north of Berwyn and of Paoli and on Henderson and Bridgeport hills. The Henderson and Bridgeport outliers, while lithologically similar to the main mass of mica-schist, can not be positively correlated with that formation. Their relation to limestone of Chazy age, as seen in the Schuylkill River cut, is such as to admit of the interpretation either of an interbedded structure or of an overlying synclinal structure, such as the mica-schist must possess.

Character of the formation and stratigraphic relations.—The formation of the northwestern area is lithologically a quartz-muscovite-schist, which frequently contains considerable iron hydroxide. When fresh it exhibits a lustrous silvery surface and a blue-gray or green-gray color. On weathering, the color alters to a reddish-yellow and the rock splits readily into foliæ. The quartz is completely wrapped about by the mica, which alone shows on cleavage planes. This formation is evidently the source of the small pockets of limonite ore which are found between it and the limestone.

The chief constituents of this mica-schist are quartz, muscovite, orthoclase, and chlorite. Quartz occurs in interlocking areas, which show undulatory extinction and other pressure effects in their form and arrangement. Orthoclase occurs in considerable areas, but it is not an important or characteristic constituent. A micaceous chlorite is uniformly distributed through the rock, interspersed with wavy lamellæ of muscovite. Plagioclase, biotite, magnetite, ilmenite, apatite, and pyrite are accessory constituents. In the neighborhood of an intrusive gabbro on the south muscovite occurs in large areas, giving a somewhat spangled appearance to the rock, and garnets, staurolite, and tourmaline are developed. The lowest member of this formation is decidedly calcareous and also more silicious than the upper members. In some localities there is interbedded a quartz-schist (or, more rarely, a quartzite) which closely resembles the Cambrian quartzite. The mica-schist of the south Chester Valley hills overlies the Chester Valley limestone. The structure of the hills is evidently synclinal, though cleavage and fissility are very pronounced and stratification is often completely obscured. Parallel structures prevail on the limbs of the syncline and cross-structures in the trough.

This formation is typically exposed in the ravine cut through the south Chester Valley hills by Gulf creek (see plate 52).

The mica-schist is considered to be Ordovician in age on the ground of its stratigraphic relations with Cambro-Ordovician limestone. That it overlies the limestone without faulting and probably without unconformity is indicated by the persistence of the geodiferous silicious bed along the contact of the two formations, and by the lithologic gradation which may be seen between the limestone and schist.

Thickness.—The structure of the formation in the south Chester Valley hills indicates a thickness not exceeding 500 feet.

Distribution of the mica-gniess.—The mica-gneiss of the southeastern area extends north and south, from Trenton, where it passes under cover, to and into Cecil county, Maryland.* West and east it extends from Buck ridge to the Delaware, expanding to the southwest and, where Buck ridge disappears as a marked topographic feature, it appears to grade across the strike into the mica-schist.

The width of exposure thus varies from less than a mile near Trenton to more than 40 miles on the Maryland boundary. The formation has been intruded by large bodies of granitic, gabbroitic, pyroxenic, and peridotitic material, lending it a massive and igneous aspect in the neighborhood of these intrusives. Aside from these contacts, the mica-gneiss is manifestly a stratified formation of a more or less heterogeneous character.

This heterogeneity is both local and regional, and, together with the presence of igneous intrusives, has been the occasion of the separation

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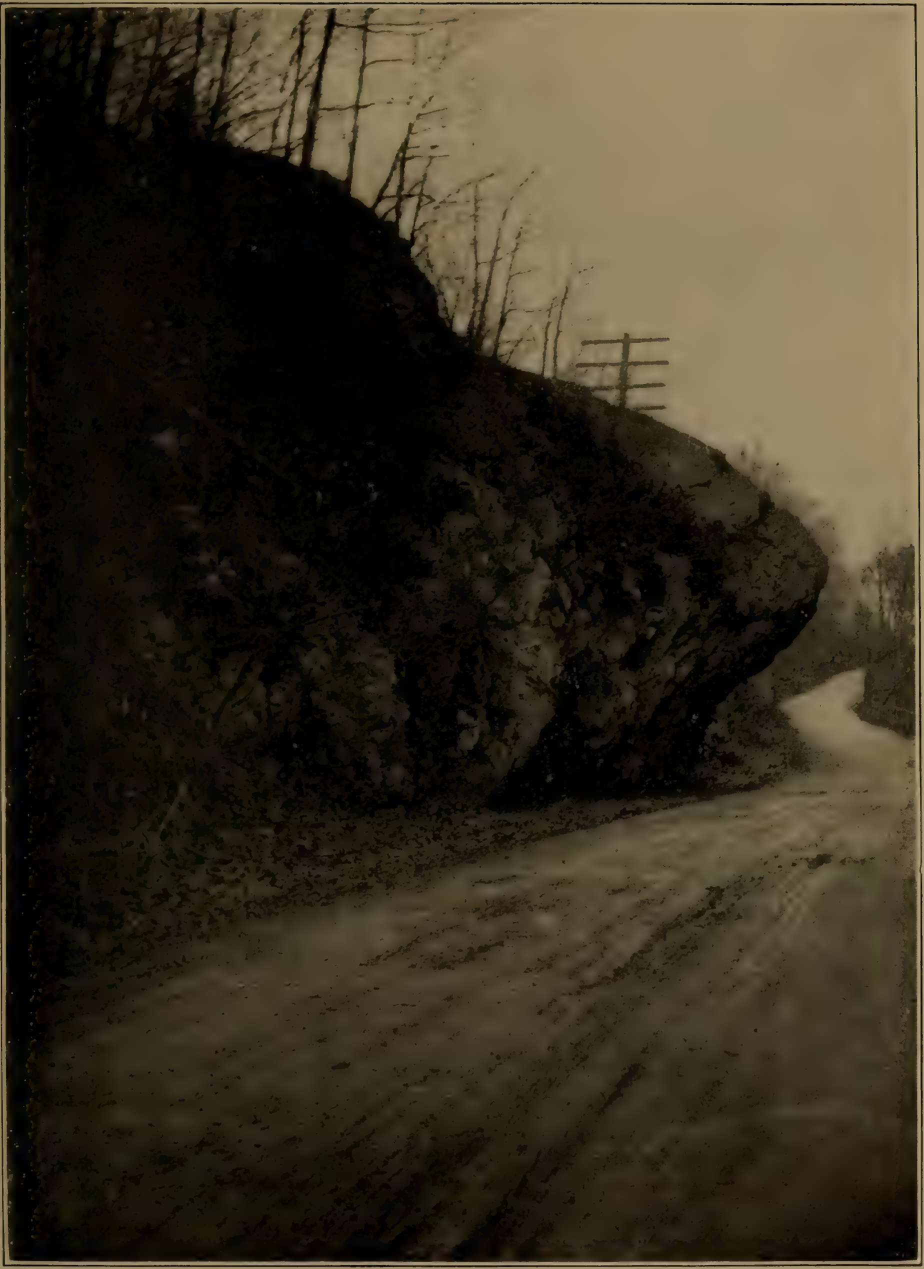
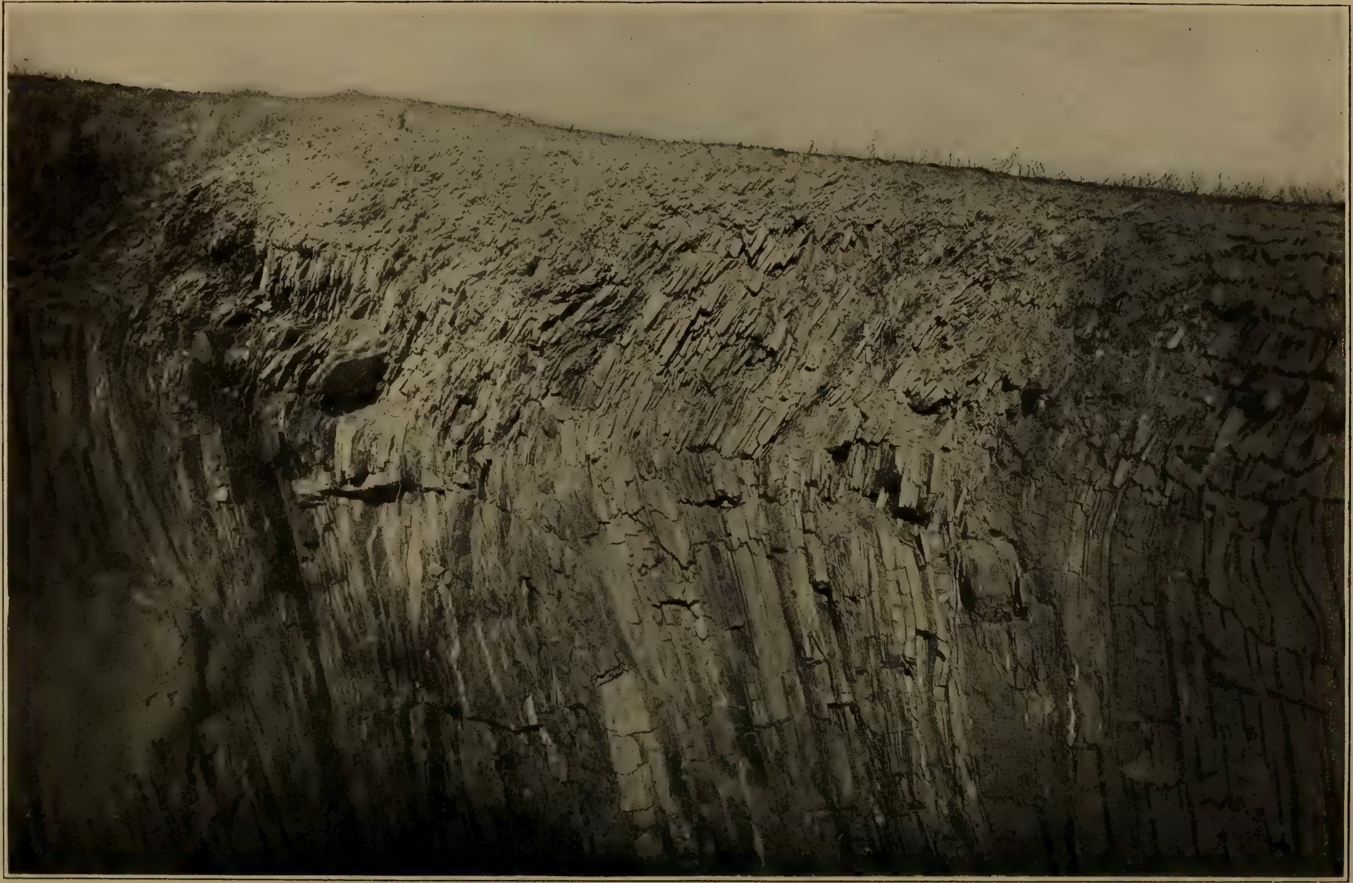
* F. Bascom: The geology of the crystallines of Cecil county. Cecil County, Maryland Geol. Survey, pp. 87-90, 103-108; also Atlas.



WISSAHICKON MICA-SCHIST

Gulf Creek ravine in South Chester Valley hills, Montgomery county, Pennsylvania



WISSAHOCKEN MICA-GNEISS WITH ISOCLINAL DIP

Schuylkill river, Montgomery county, Pennsylvania. Photographed by E. B. Harden of the formation by earlier surveys into three formations—the Chestnut hill, Manayunk, and Philadelphia gneisses.

Character of the formation and stratigraphic relations.—With local variations, which are later indicated, the formation may be described as a medium to coarse-grained gneiss, characterized by an excess of mica.

The chief constituents of the formation are quartz, feldspar, both orthoclase and plagioclase; green or brown biotite, and muscovite. Magnetite, apatite, zircon, tourmaline, garnets, andalusite, sillimanite, and zoisite are accessory constituents. The more gneissic beds contain abundant orthoclase and plagioclase, which, whenever tested, proved to be an acid variety between oligoclase and andesine (Ab_3An_1). The rock is perfectly crystalline, the quartz fresh, and occurring in interlocking areas. The freshness of the crystallization and the absence of pressure effects on the constituents indicate a recrystallized sediment.

The belt passing through Chestnut hill and Bryn Mawr is composed of beds which are alternately micaceous and quartzose, and often bear a marked similarity to the mica-schist of the south Chester Valley hills (see plate 53). It is also very garnetiferous in the neighborhood of the peridotite intrusives, and for this reason has been called the "garnetiferous mica-schist." Even in this belt the formation is not free from feldspar, and in the direction of Manayunk and Philadelphia massive gneissic strata interbedded with micaceous and quartzose layers become increasingly prominent, and garnets are replaced by andalusite and sillimanite.

Within the contact zone of the most northerly of the serpentine dikes the mica-gneiss has locally altered to a muscovite-schist. It contains large lustrous areas of muscovite, which have won for it the designation "spangled mica-schist." It is silicious, light colored, coarsely crystalline, and splits readily.

The rock possesses a chemical composition, as shown by analysis,* which resembles that of a slate, and bears out the field and petrographic determination of the formation as of sedimentary origin.

The high alumina percentage, low alkali percentage, and the preponderance of magnesia over lime shown by these analyses are all characteristic of silicious argillites, while in all feldspar-bearing igneous rocks, on the other hand, lime dominates the magnesia.

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* Bascom: Op. cit., p. 116.

Analyses of Wissahickon mica-schist and mica-gneiss

	1	2	3	4	5	6
SiO_2	43.81	43.10	39.35	56.40	66.13	73.68
Al_2O_3	27.52	30.86	31.92	19.76	15.11	12.49
Fe_2O_3	7.30	7.28	2.19	4.35	2.52	2.10
FeO	Trace.	....	9.00	4.40	3.19	2.22
MgO	1.77	1.80	3.08	3.11	2.42	2.04
CaO	0.19	....	....	0.09	1.87	0.56
Na_2O	0.56	0.66	1.98	5.82	2.71	2.97
K_2O	8.81	6.87	5.26	1.27	2.86	2.91
H_2O+ H_2O-	7.52	5.91	6.05	3.37	1.55 .24	1.34
CO_2	....	....	....	....	None.	....
TiO_2	3.78	3.28	1.20	1.05	0.82	0.81
ZrO_2	....	....	....	....	Not estimated.	....
P_2O_5	0.13	Trace.	0.49	0.37	0.22	0.12
Cl	....	....	....	....	Not estimated.	....
F	....	....	....	....	Not estimated.	....
S	....	....	....	....	0.03	....
Cr_2O_3	....	....	....	....	None.	....
NO	....	....	....	Trace.	Trace.	....
MnO	....	....	0.06	....	0.20	0.18
BaO	....	....	....	....	Trace.	....
SrO	....	....	....	....	Trace.	....
Li_2O	Trace.	....	....	Trace.	None.	....
	101.39	99.76	100.58	99.99	99.87	101.42

Analyses 1. Mica-schist between Gulf Mills and Hitner's marble quarry.

Analyses 2. Mica-schist between Gulf Mills and King of Prussia.

Analyses 3. Mica-schist 1,222 feet from "Bird in Hand" tavern, on road from Gulf Mills to Bryn Mawr.

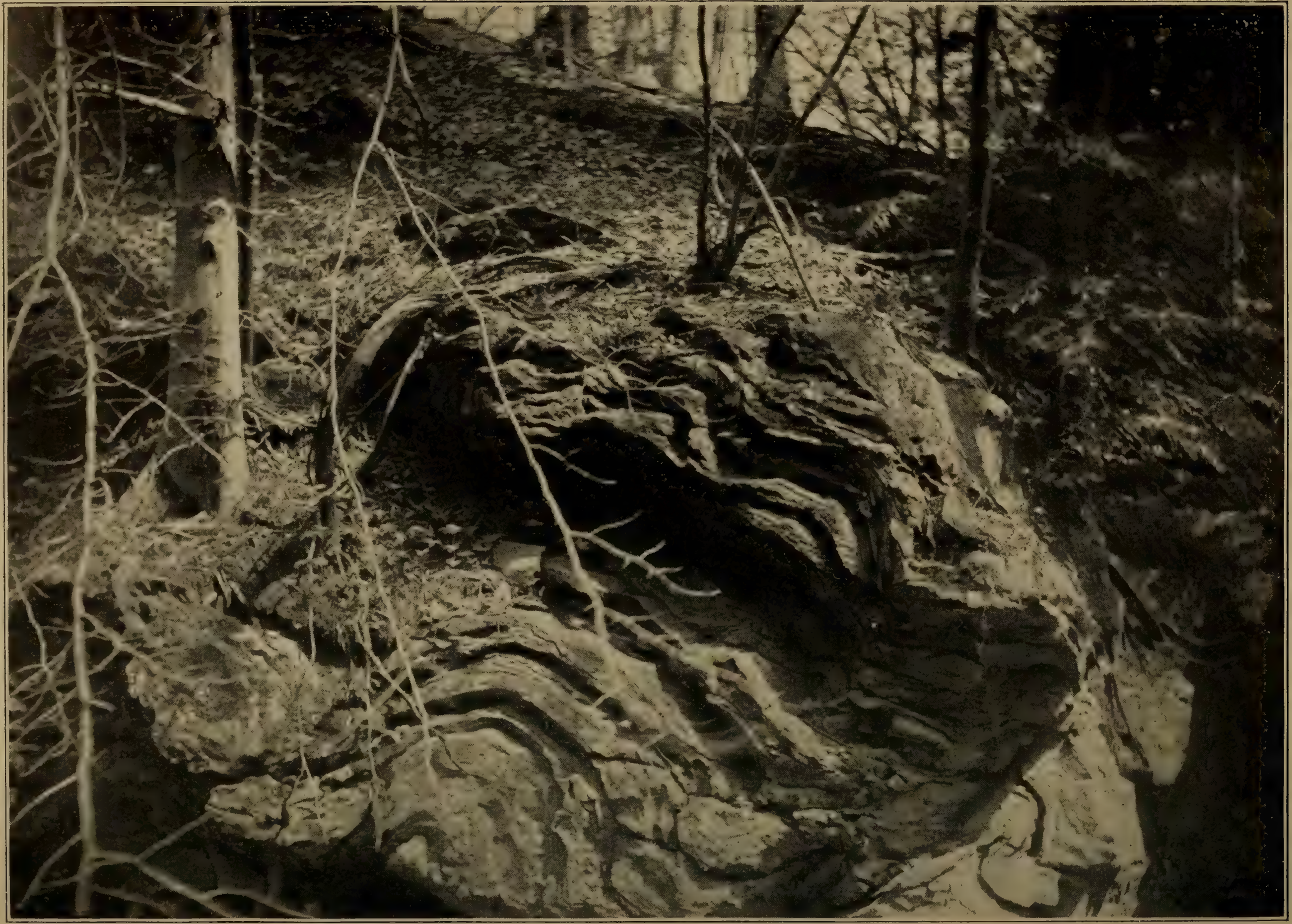
Analyses 4. Mica-gneiss, Neshaminy creek.

Analyses 5. Mica-gneiss. Analysis made from four samples representing four localities.

Analyses 6. Mica-gneiss, Neshaminy creek, below (4). Analyses 1, 2, 3, 4, and 6 made by F. A. Genth, Jr., volume C 6, Second Geological Survey of Pennsylvania, pp. 132, 133, 108, 109. Analyses 5 made by W. F. Hillebrand, of the United States Geological Survey.

Cleavage and fissility are always marked features of the mica-gneiss, but most marked where the formation is least feldspathic and most micaceous. The micaceous variety readily splits into fragments aptly likened by Professor Rogers to "half-rotted fibrous wood." Stratification is often obscure in the material poor in feldspar, but where fresh rock is exposed bedding can usually be discerned.

The beds show minute crumpling and both gentle and steep folding (see plate 54). In the latter case cleavage, fissility, and bedding are



CRUMPLED WISSAHICKON MICA-GNEISS

Wissahickon creek, Philadelphia county, Pennsylvania parallel structures and inclined 60 to 70 degrees southeast (see plate 53). Anticlines and synclines alternate. The strike is north 50 to 80 degrees east with a varying pitch of 5 to 25 degrees.

There are many abandoned quarries in the mica-gneiss, and large quarries are in active operation between Chestnut hill and Germantown and on Cobbs creek west of Haverford. Many country town homes are built of this material. It has been used in college halls at Bryn Mawr, Princeton, Williams, and Vassar.

Thickness of the mica-gneiss.—It is not possible to determine with any exactness the thickness of the mica-gneiss. The isoclinal folding and constant variation in beds give a false idea of its thickness, which probably lies between 1,000 and 2,000 feet.

Name.—The Wissahickon creek affords an excellent section across the strike of the formation. Because the mica-gneiss is so finely exposed in the gorge of this stream it is called the Wissahickon mica-gneiss (see plate 54).

Stratigraphic relations.—The determination of the age of the mica-gneiss rests wholly for its evidence on the stratigraphic relations which the formation sustains with fossil-bearing sediments. The mica-gneiss contains within itself no clue to its age.

In northern Delaware and in the southwestern part of Chester county, Pennsylvania, limestone is exposed in several abandoned quarries. Crystalline limestone is brought to the surface by means of anticlinal structures and bears on the limbs of the anticlines conformable beds of mica-gneiss similar to the Wissahickon mica-gneiss. This relation is also shown in several limestone outcrops west of West Chester, Pennsylvania. In the latter localities the limestone is in line with the strike of the Chester Valley limestone, and is without doubt stratigraphically continuous with that formation beneath the mica-schist. There is no evidence, except very locally, of thrust movement between limestone and mica-gneiss. The number and extent of such occurrences of gneiss and limestone, and the large area involved, renders an overturned structure improbable. Presumptively the mica-gneiss lies above the limestone. Not only does the mica-gneiss bear this stratigraphic relation to presumably Cambro-Ordovician limestone, but, as has been pointed out, it grades across the strike into the Ordovician mica-schist just described. This lithologic gradation and stratigraphic continuity can be seen in sections furnished by Brandywine creek and Buck run.

It has been affirmed by G. H. Williams* that the eruptive material is confined to the eastern belt of gneiss and is not found in the recognized Paleozoic material to the west of Buck ridge, and this affirmation has been made the ground for inferring an igneous unconformity between the western Paleozoics and eastern gneisses. One mile northwest of Romansville and 9 miles west of West Chester there occur intrusives in the Ordovician mica-schist overlying the Cambro-Ordovician limestone, gabbro and peridotite altered to serpentine and precisely similar to intrusives in the Wissahickon mica-gneiss.

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* "The petrography and structure of the Piedmont plateau in Maryland." Bull. Geol. Soc. Am., vol. 2, 1891, p. 316.

The Huntington Valley thrust fault explains the absence of limestone exposures between the Cambrian quartzite and the mica-gneiss in the otherwise normal succession of the Paleozoic series. On these grounds, because of stratigraphic relations to presumably Cambro-Ordovician limestone, because of passage into Ordovician mica-schist, and in view of the absence of any evidence of unconformity between it and recognized Paleozoics, the mica-gneiss is provisionally held to be Ordovician in age.

Correlation.—The Wissahickon mica-schist and the Wissahickon mica-gneiss are to be correlated with the Berkshire schist of New England, the Hudson schist of New York, the phyllite and the Wissahickon mica-gneiss of Maryland. It is stratigraphically continuous with the latter formation. The Wissahickon mica-schist is H. D. Rogers' "primal upper slate" and the "Cambrian phyllite" of the Second Geological Survey of Pennsylvania. The Wissahickon mica-gneiss comprises, together with intrusive granite and gabbro, H. D. Rogers' "first and second gneiss belts" and the Chestnut Hill, Manayunk, and Philadelphia mica-schists and gneisses, considered pre-Cambrian and Cambrian in age, of the Second Geological Survey of Pennsylvania.

STRUCTURE OF THE SEDIMENTARY FORMATIONS

The Triassic formations of the Piedmont plateau show a gentle northwest dip and normal faulting. The pre-Cambrian and Paleozoic sediments of the whole width of the Piedmont plateau, ignoring the Triassic formations which conceal a broad central area, apparently form an anticlinorium of the first order, which has brought to the surface pre-Cambrian gneiss along a central axis striking northeast, flanked by Cambrian quartzite, Cambro-Ordovician limestone, and Ordovician mica-schist. The surface outcrop of these formations is interrupted parallel to the strike and controlled in width by the minor transverse folding, which, alternately bending the axis of the anticlinorium in a low trough or raising it in a low arch, bring successively younger or successively older formations to the surface.

There is, then, an anticlinorium of the first order compounded of anticlinoria and synclinoria of the second order. These are in turn composed of anticlines and synclines and secondary and tertiary anticlines and synclines. The axes of the major folds strike northeast-southwest and the axes of the minor folds northwest-southeast.

The crystallines of the southeastern belt emerge from beneath the Trias and on the southeast flank of the great anticlinorium to form the Chester Valley synclinorium. The limbs of the synclinorium, separating it from the bounding anticlinoria, are formed by the Chickies quartzite. This formation, resisting erosion more successfully than the limestone, gives rise to the hills which bound Chester valley in its extension to the northeast. These hills are thus monoclinal in structure.

To the southwest the southeastern limb is first partially faulted out and then concealed by a younger formation, which, appearing first at Conshohocken, expands southwestward and forms the south Chester Valley hill. This expansion is due to a general southwest pitch of the synclinorium, caused by minor folding. It is this southwest pitch that brings the nose of the synclinorium to the surface in the northeast end of Chester valley and causes the expansion northwestward of the oldest formation, the Baltimore gneiss. The character of the synclines and anticlines which compose the synclinorium is inferred from that of the secondary folding on the limbs of anticlines and synclines. These secondary folds (see plate 51) in the Chester Valley limestone are isoclinal in character, the isoclinal dips varying from 45 to 80 degrees southeast. The more pliant mica-schist shows closer folding and a crumpling absent in the limestone and quartzite.

The synclinorium is bounded on the southeast by a fan-shaped anticlinorium, which brings to the surface the Baltimore gneiss. The southwest limb of this anticlinorium is faulted, and west of the Schuylkill the northwest limb is also faulted. This fault, called the Cream Valley fault from the local name of the valley which it marks, brings about the almost complete disappearance of the limestone and quartzite of the northwest limb of the anticlinorium. Limestone appears in Mechanicsville, west of the Schuylkill, on the crest of a subordinate anticline, and is then cut out by a thrust fault, which has brought the Baltimore gneiss on a level with it.

The anticlinal character of the folding of the Baltimore gneiss is shown in the Schuylkill river section. The secondary folding is steep on either limb of the anticlinorium and gentle in the center. The dips vary from verticality to a steep southeast dip on the northwest limb and are predominatingly northwest on the southeast limb, thus producing a somewhat fan-shaped anticlinorium. There is a very gentle northeast pitch indicating a subordinate minor fold. The only other locality where the structure of the Baltimore gneiss can be seen is in a cut of the

Cresheim branch of the Pennsylvania railroad near Laverock. Here the gneiss is vertical to 60 degrees southeast. Elsewhere the gneiss when exposed is either so decayed or so thoroughly penetrated by the gabbro as to obscure stratification and the record of the folding to which it has been subjected.

The fault on the southeast limb of the anticlinorium, or the Huntington Valley fault, is thought to hade* to the northwest and has thus thrust the Baltimore gneiss on the eroded surface of the Paleozoics. The mica-gneiss, like the mica-schist, susceptible to crumbling, shows much secondary folding. This fact, together with the absence of recognizable beds, obscures the primary folding, and while there are evidences of two synclinoria and one anticlinorium southeast of the Huntington Valley fault line, they can not be distinctly traced in the Philadelphia district. The presence of intrusives and the cover of Pleistocene materials obscure the structure of the mica-gneiss. On the Wissahickon, where the gneiss is well exposed, the dips are often very gentle and predominatingly northwest (see plate 54). The cleavage dip remains constant to the southeast.

IGNEOUS ROCKS

CLASSIFICATION

The igneous rocks of the belt are intrusive in character. They may be classified lithologically as granitic, including several distinct masses, and as gabbroitic, including the gabbro, hypersthene gabbro, norite, pyroxenite, peridotite, meta-gabbro, meta-pyroxenite, and meta-peridotite, or serpentine, the diabase, and meta-diabase.

GRANITE-GNEISS

Distribution.—This is an igneous intrusive of a granitic character, which is well exposed on the west side of the Schuylkill. Striking east in the direction of some scattered outcrops of granite, the main mass of granitic material disappears somewhat abruptly on the east bank of the river at the falls of the Schuylkill, but expands southwestward toward the Delaware river, where it disappears as a surface formation beneath a cover of gravels. Its presence beneath the gravel is attested by numerous large quarries in the formation, on Crum and Ridley creeks, in the neighborhood of the Delaware. West of this body of granite-gneiss a similar rock occurs southeast of Lima and can be traced to Glen Riddle. The Wilmington and Baltimore Central divisions of the Pennsylvania railroad gives a section through this granite and serpentine between Glen Riddle

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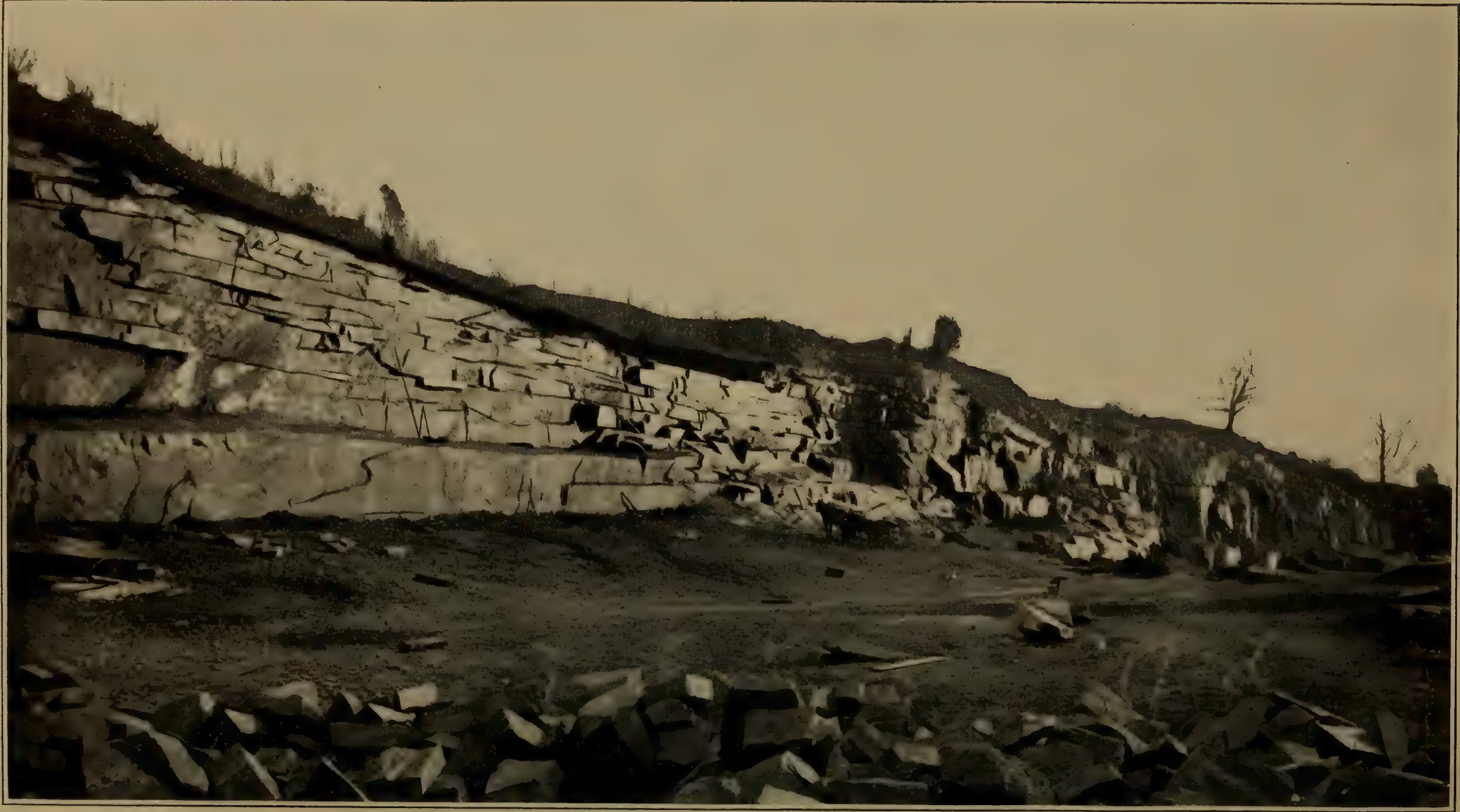
*The writer is indebted to Mr George W. Stose, of the U. S. Geol. Survey, for suggestions as to the direction of hade.



GRANITE-GNEISS IN LEIPERVILLE QUARRY

Delaware county, Pennsylvania. Photographed by E. B. Harden and Lenni Mills. Both rocks are greatly decomposed, but the facts indicated by the section seem to be that the granite is the older intrusive, and that the serpentine or meta-peridotite intrudes through the granite and lies on top of it as a sheet. The relation of the outcrop of granite and serpentine to the topography also indicates that the latter rock overlies the granite.

East of the main body of granitic rock, granite-gneiss emerges from a cover of mica-gneiss on Pennypack creek near Vereeville and at Holmesburg, where it has long been quarried.

A granite-gneiss also occurs in west Philadelphia and Fairmount park. It was temporarily exposed in the neighborhood of Powelton Avenue station when the station was removed and the railway cut widened.

A large body of granite-gneiss constitutes the greater part of the Piedmond district of Cecil county, Maryland. This has been known as the Port Deposit granite-gneiss.

Its areal distribution, relations to the gabbroitic eruptions of the district, and petrography are discussed elsewhere.* The relations of gabbro and granite in Cecil county are similar to those farther to the northeast. Dikes of the former intrude in the granite and indicate a greater age for the granite.

The general lithologic similarity of these isolated outcrops of granite-gneiss suggests a common magmatic origin.

Character.—The rock of the main mass of granite is medium to coarse grained, typically gneissoid, but often massive away from the periphery, which is characteristically porphyritic. The phenocrysts are light, flesh-colored orthoclases, which show orientation of their longest axes parallel to the strike of the rock and which range from ½ to 1¼ inches in length. The chief constituents of the rock are quartz, feldspar, biotite, and hornblende. Muscovite is more rarely present. The feldspar is chiefly orthoclase and microcline and subordinately oligoclase (ab_6an_1). Accessory constituents are titanite, apatite, epidote, and actinolite.

The rock shows the result of pressure in the production either of microcline structure, or of granulation in the feldspar, in the granulation of quartz, and in the orientation of the constituents. Along the contacts with the bounding rock, mica-gneiss, an injection gneiss has been produced by the penetration of the acid magma parallel to planes of fissility of the mica-gneiss.

In the Pennsylvania Railroad cut, 1⅛ miles southeast of Overbrook station, a contact facies of the granite-gneiss is exposed. The porphyritic granite passes abruptly into a close grained aphanitic tough, light, gray rock, which breaks with a conchoidal fracture. Quartz, feldspar, colorless augite, and titanite are the chief constituents. The feldspar is bytownite (ab_1an_5). The structure is microgranulitic. The exposure is some 500 feet in width, and no other exposure of this type has been found. This may be a dike: if, on the other hand, it represents a contact zone, the more rapid cooling and earlier crystallization which would take place along the periphery of the intruding granite may explain its finer texture and the more basic character of its feldspar.

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* F. Bascom: Op. cit., pp. 90-92, 108, 117-119.

The formation furnishes a good building stone, and has therefore been extensively quarried. There are quarries at the falls of the Schuylkill on the west bank of the river, at Overbrook, southwest of Overbrook on Indian creek, at Kelleyville, and along the lower courses of Ridley and Crum creeks (see plates 55, 56). In the Ridley and Crum Creek quarries the rock is non-porphyritic, of an even, medium grain, light colored, and is characterized by the presence of both micas. This rock has not been separated by the previous surveys from the Manayunk and Philadelphia gneisses.

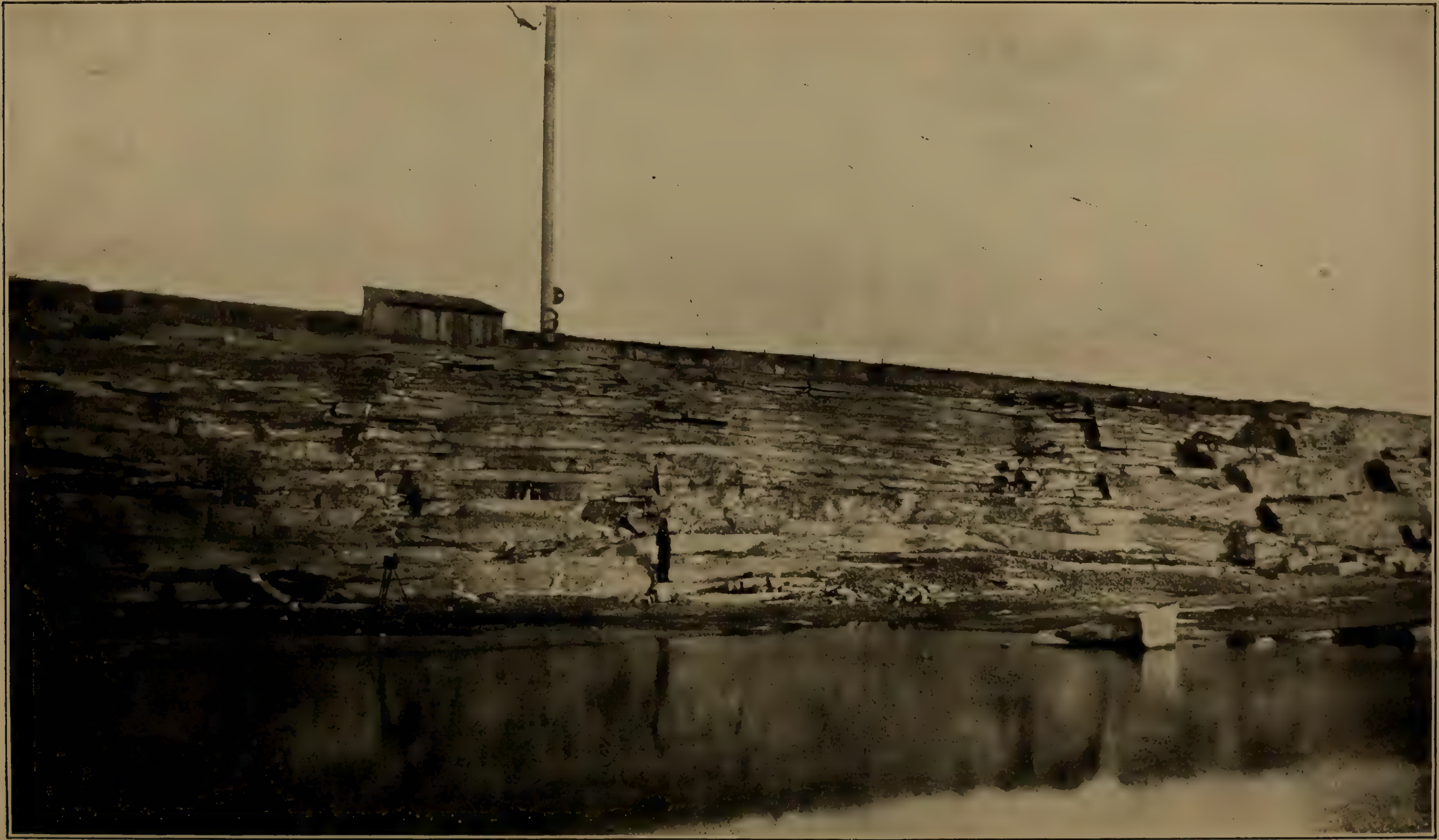
Two analyses have been made of the Port Deposit granite. They are as follows:

	I.	II.
SiO_2	73.69	66.68
Al_2O_3	12.89	14.93
Fe_2O_3	1.02	1.58
FeO	2.58	3.23
MgO	0.50	2.19
CaO	3.74	4.89
Na_2O	2.81	2.65
K_2O	1.48	2.05
H_2O	1.06	H_2O + 1.09 H_2O − 0.16
TiO_2	....	0.50
P_2O_5	....	0.10
MnO	....	0.10
BaO	....	0.08
SrO	....	Trace.
Li_2O	....	Trace.
	99.77	100.23

I. Biotite-granite or quartz-monzonite. Analysis made by William Brownell in the chemical laboratory of Johns Hopkins University.

II. Hornblende-biotite-granite or quartz-monzonite. Analysis made by W. F. Hillebrand in the laboratory of the United States Geological Survey.

G. P. Grimsley: Journal of Cincinnati Society of Natural History, volume xvii, 1894, pages 88–89.



GRANITE-GNEISS IN WARDS QUARRY

Delaware county, Pennsylvania. Photographed by E. B. Harden

These analyses give the following norms:

	I.	II.
Quartz	41.28	27.84
Orthoclase	8.90	12.23
Albite	23.58	23.06
Anorthite	18.07	22.24
Diopside	0.25	1.36
Hypersthene	5.13	8.80
Magnetite	1.39	2.32
Ilmenite	....	0.91
Apatite	....	0.34
H_2O	1.06	1.25
	99.76	100.45

The more acid facies of the Port Deposit granite is a biotite-grano-susquehannose* (class I, order 3, rang 3, subrang 4). This means that the salic constituents preponderate; that of the salic constituents quartz and feldspar are present in nearly equal amounts; that of the feldspars the alkali molecules are equal to the lime molecules; that of the alkalies soda is dominant, and, finally, that the texture is megascopically hypautomorphic granular, and that the only abnormative mineral present in the rock is biotite.

The more basic facies falls in class II, order 1, rang 3, subrang 4. Like the acid type, it is dosodic and alkalicalcic, but differs from the other facies in the fact that the salic minerals are merely dominant, but not preponderating, and feldspar is dominant over quartz. The texture of the rock is hypautomorphic granular, biotite is the only abnormative mineral present, and is a critical mineral. The name of the rock is therefore a biotite-grano-tonalose.

GABBRO (GABBRO, HYPERSTHENE-GABBRO, NORITE, META-GABBRO)

Distribution.—This is a great igneous body which, with many ramifications and varying petrographic facies, intrudes into the Atlantic belt of crystallines from Virginia to New York.

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* The name *susquehannose* is suggested by the writer for subrang 4 of rang 3, order 3, class I. This subrang, in the absence of any strong claims for preeminence on the part of the species falling in it, was left unnamed by the authors of the quantitative system of nomenclature.

The appropriateness of susquehannose lies not only in the fact that large quarries in this rock species have long been worked on the Susquehanna river, but also that calcic granites of this general type are especially abundant in the region drained by that stream. The attention of the writer has been called in this connection by Dr H. S. Washington to the fact that there is a zone of calcic rocks striking parallel with the Atlantic coast and showing in Labrador, eastern Canada, Adirondacks, Pennsylvania, and Maryland. East of this belt is a zone of sodic rocks showing in Ontario, New Hampshire, eastern Massachusetts, New Jersey (Beemerville), and farther south in Georgia, Texas, and Tamaulipas, Mexico.

The high calcic content of the other igneous types of the Pennsylvania district will be made evident in their discussion.

It is an important formation in Maryland, Delaware, and southeastern Pennsylvania, where it intrudes alike into pre-Cambrian Baltimore gneiss and into Paleozoic limestone and mica-gneiss.

In the Pennsylvania belt its maximum development is in the southeast. From the Susquehanna river and from the region about Wilmington, Delaware, it extends northeast, forming the main mass of Buck ridge, where it shows itself at the surface in exceedingly irregular areas. It is intimately associated with the Baltimore gneiss, and has so affected this formation along contacts as to produce an appearance of gradation from banded gneiss to massive gabbro.

There are many instructive exposures of gabbro and Baltimore gneiss. They all suggest the intercalation, along the periphery of the gabbro mass, of the former rock between the beds of the latter and the subsequent folding of both materials. The penetration of the gneiss by the gabbro is quite irregular. Thin sheets swell into large masses, which, on exposure, weather into spheroidal boulders. Because of this peculiar injection of the gneiss by gabbro, gabbro boulders may appear sporadically in areas where gneiss is the prevailing formation at the surface, and *vice versa.*

At Glen Mills, a few rods south of a large quarry in gabbro, an abandoned quarry shows gneiss and gabbro interbedded, yet the gneiss does not appear as a surface formation.

Under these conditions it is impossible, in fixing the boundaries of these two formations, not to include some gneiss within the gabbro area, while gabbro boulders may be seen within the gneiss area and gabbro injections appear in rock cuts, though not prevailing at the surface. This is particularly true of the areas northwest of Media.

The Baltimore gneiss and the gabbro have not before been separated in the Pennsylvania Piedmont. They alike give rise to a relatively elevated rolling country, with irregular, rounded eminences.

Dark-colored boulders of disintegration, with rusty exteriors, strew the fields and afford almost the only indication of the underlying rock. The gabbro boulders are exceedingly tough, except along contacts with the gneiss, where the development of hornblende and mica renders them more schistose and more easily attacked mechanically.

Character.—The gabbro is a medium-grained massive rock,* possessing either a bronzy-gray or a greenish-gray color, depending on the character of the ferromagnesian constituent.

Quartz, pyroxene, and feldspar may usually be determined in the hand specimen. The gabbro is a typical hypersthene-augite-plagioclase-

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* For full petrographic description of the Cecil County gabbro and norite, see Bascom, op. cit., pp. 121–132.

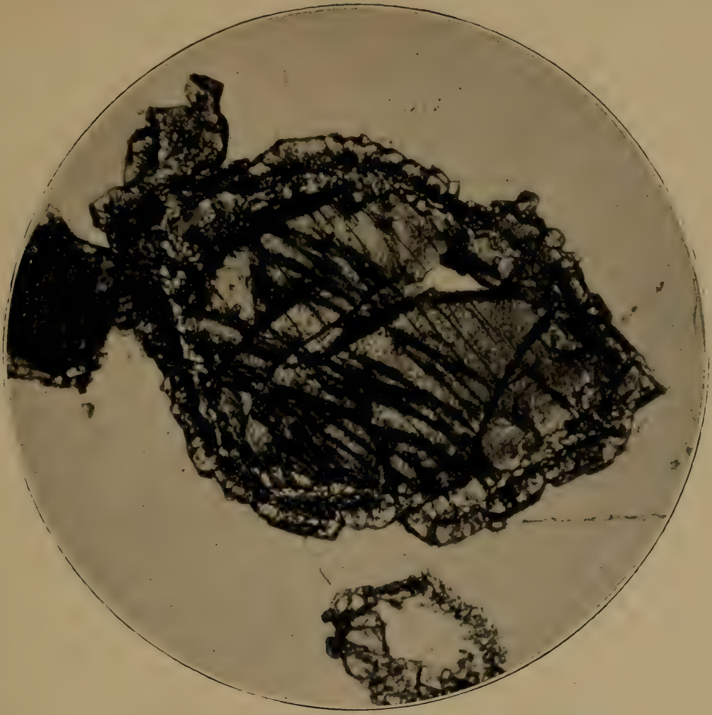


FIGURE 1.—HYPERSTHENE WITH GARNET VEIN. PPL × 67

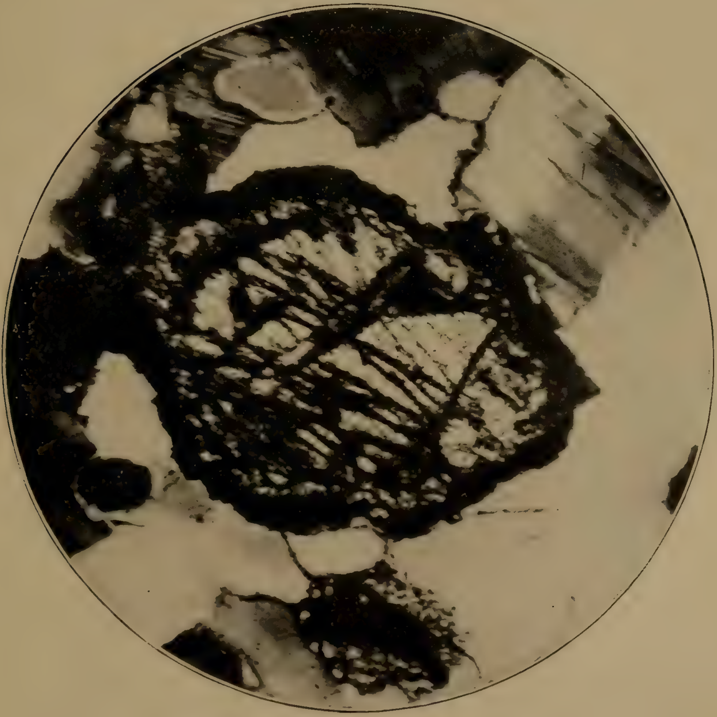


FIGURE 2.—THE SAME WITH CROSSED NICOLS. × 61

PHOTOMICROGRAPHS OF HYPERSTHENE-GABBRO

Wayne, Delaware County, Pennsylvania. Photographed by F. J. Keeley

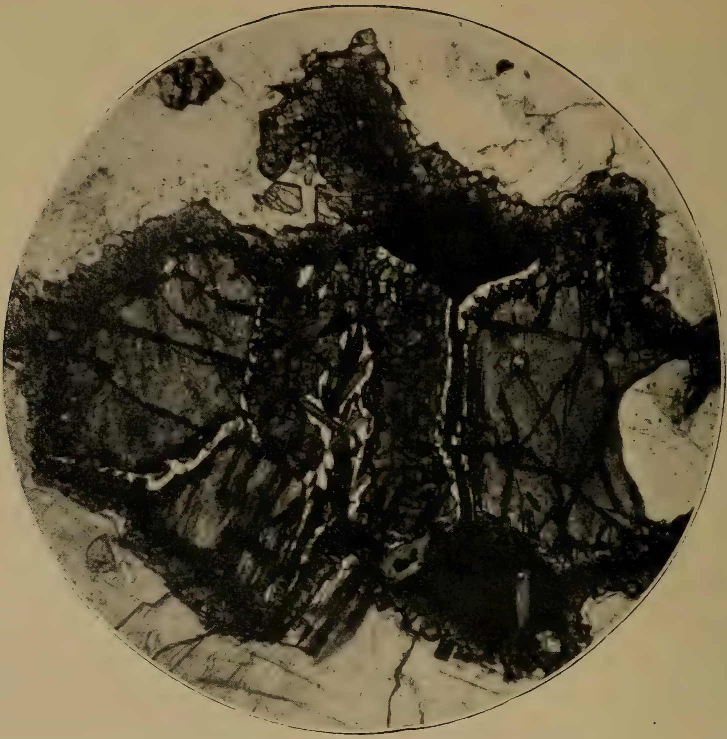


FIGURE 1.—HYPERSTHENE WITH GARNET VEIN. PPL. × 67

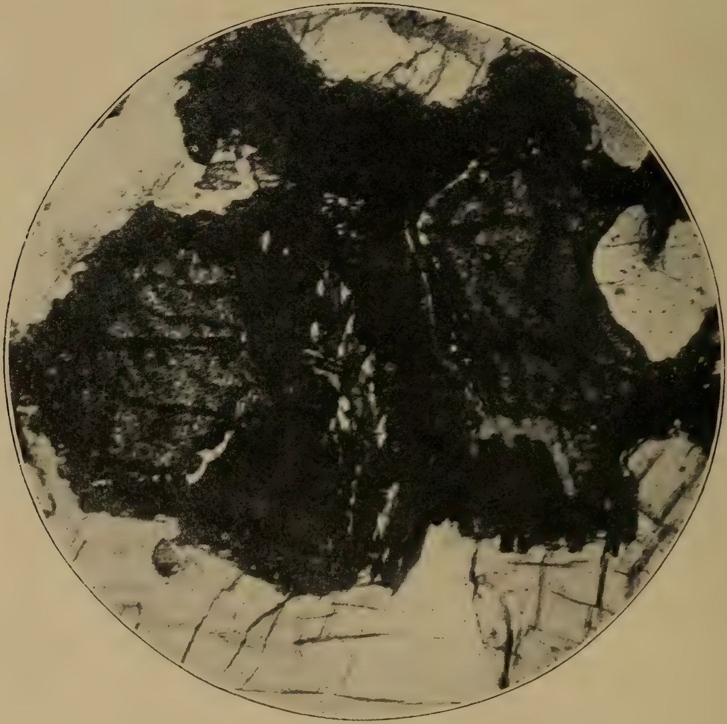


FIGURE 2.—THE SAME WITH CROSSED NICOLS AND GYPSUM PLATE. × 65

PHOTOMICROGRAPHS OF HYPERSTHENE-GABBRO

Two miles southeast of Berwyn, Chester county, Pennsylvania. Photographed
F. J. Keeley

rock, with accessory quartz, biotite, hornblende, magnetite, apatite, titanite, pyrite, pyrrhotite, garnet, and orthoclase. Exclusively decomposition minerals are actinolite, chlorite, and serpentine. Quartz is very variable in amount, ranging from 0 to 30 per cent.

The pyroxenic constituent may be exclusively hypersthene, chiefly hypersthene, or less frequently, chiefly augite or exclusively augite or diallage. It constitutes from 10 to 40 per cent of the rock.

The plagioclastic constituent is labradorite or labradorite-bytownite, and varies from 5 to 50 per cent of the rock. Between the pyroxene, whether hypersthene or augite, and the labradorite there occur reactionary peripheral bands of garnets. Between the garnets and the pyroxene there is a narrow zone of quartz and hornblende. Hypersthene and the anorthite molecule will produce hornblende, quartz, and common garnet (an isomorphous mixture of grossular, almadine, and pyrope). In the case of the monoclinic pyroxene the feldspar molecule is not needed and lime is liberated. These garnet rims are the most striking petrographic features of the gabbro (see plates 57, 58, and 59).

Wherever the gabbro has been subjected to pressure, as along the periphery of the intrusive mass, pyroxene is replaced, chiefly by green hornblende and subordinately by biotite. Such a margin of hornblende-gabbro is so marked a feature of the Cecil County gabbro mass that it can be mapped as a separate formation. A more or less schistose structure accompanies the development of these two minerals. Along the contacts hornblende also accompanies biotite as a constituent of the gneiss. This contact phenomenon increases the difficulty of separating the two formations.

The gabbro is associated with and, through decrease in feldspar, grades into pyroxenite or, with the addition of olivine, into peridotite.

The youngest material into which the gabbro intrudes is the Ordovician mica-schist. The gabbro is therefore post-Ordovician in age. Its relations to the granite are such as to indicate that the granite, which is also post-Ordovician, is the earlier intrusive.

By the previous surveys it has been included with the " Laurentian gneiss " or syenite.

Determination of the rock species represented by the gabbro mass

	I.	II.	III.	IV.	V.	VI.
SiO_2	58.57	55.16	54.03	53.21	48.02	44.04
Al_2O_3	16.10	17.51	16.71	1.94	20.01	20.01
Fe_2O_3	2.89	2.62	1.37	1.44	1.13	4.22
FeO	6.12	5.83	7.70	7.92	7.29	8.61
MgO	2.33	4.35	5.66	20.78	10.05	5.01
CaO	7.39	8.50	8.84	13.12	11.42	11.68
Na_2O	2.11	1.83	2.99	0.11	0.51	1.24
K_2O	1.01	1.08	0.67	0.07	0.05	0.15
H_2O+	1.27	2.01	0.53	0.87	0.57	1.90
H_2O-	0.21	0.21	0.14	0.14	0.10	0.11
CO_2	None.	None.	0.40	0.10	0.25	None.
TiO_2	1.41	0.64	0.84	0.26	0.23	2.24
ZrO_2	0.09	0.02	Not est.	Trace.	None.	0.10
P_2O_5	0.37	0.21	0.13	Trace.	Trace.	0.52
Cl	None.	Not est.	Not est.	Not est.	Not est.	Not est.
F	Not est.	Not est.	Not est.	Not est.	Not est.	Not est.
FeS_2	Trace.	0.03 (.025)	Not est.	0.03	0.11	0.25 (.1355)
S	Trace.	....	0.09	....	....	....
Cr_2O_3	None.	Trace.	Trace.	0.20	0.03	None.
NiOCoO	None.	0.01	Trace.	0.03	0.01	0.01
MnO	0.18	0.05	0.13	0.22	0.18	0.28
BaO	Trace.	Trace.	Trace.	None.	None.	None.
SrO	Trace.	Trace.	Trace ?	None.	None.	None.
Li_2O	Trace.	Trace.	Faint trace.	....	....	Trace.
V_2O_3	0.02 (.018)	0.04 (.036)	....	0.03	0.02	0.05
Total	100.07	100.17	100.23	100.42	99.98	100.42

Norms

	I.	II.	III.	IV.	V.	VI.
Quartz	21.78	13.56	4.56	....	0.60	2.16
Orthoclase	6.12	6.67	3.89	0.56	0.56	1.11
Albite	17.82	15.20	25.68	1.05	4.19	10.48
Anorthite	31.41	36.42	30.30	4.45	51.99	48.37
Zircon	....	....	...	....	....	0.18
Diopside	2.32	4.08	10.52	48.21	3.83	5.23
Hypersthene	11.11	16.56	20.67	41.98	35.65	19.05
Magnetite	4.18	3.71	2.09	2.09	1.62	6.03
Ilmenite	2.74	1.22	1.52	0.46	0.46	4.26
Apatite	1.01	0.34	0.34	....	....	1.34
Pyrite	....	0.03	0.24	....	....	0.25
Olivine	....	....	....	0.31	....	....
H_2O	1.48	2.22	0.67	1.01	0.67	2.01
Total	100.97	100.01	100.48	100.12	99.57	100.47

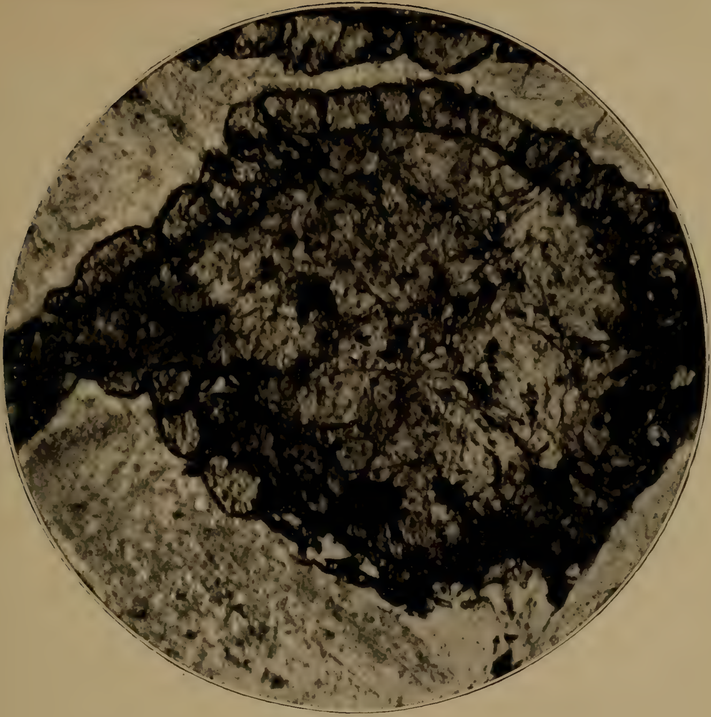


FIGURE 1.—PYROXENE CORE REPLACED BY HORNBLENDE. PPL. × 95

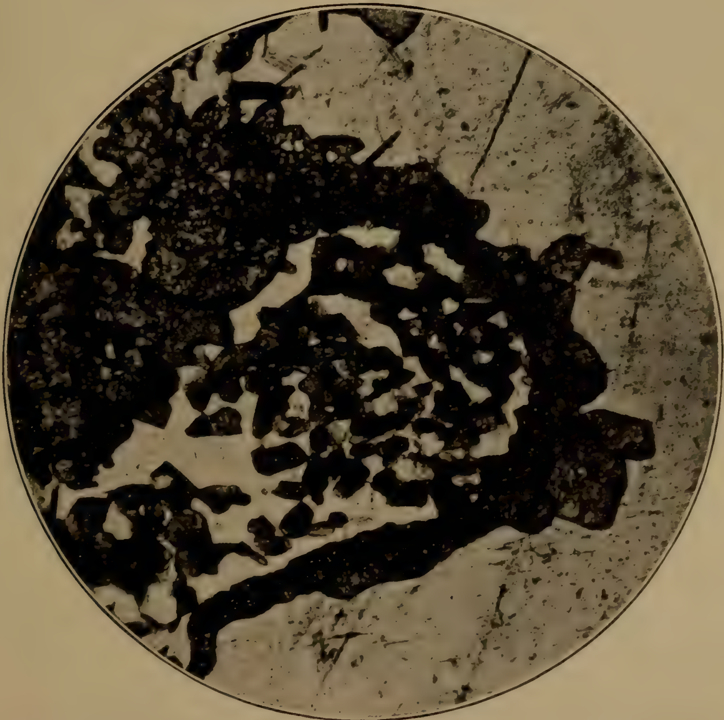


FIGURE 2.—PYROXENE CORE REPLACED BY HORNBLENDE, BIOTITE, AND QUARTZ. PPL. × 90

PHOTOMICROGRAPHS OF META-GABBRO

Figure 1 from 1 mile east of Waterloo mills, and figure 2 from 2 miles southeast of Berwyn, Chester county, Pennsylvania. Photographed by F. J. Keeley

I. Quartz-biotite-hornblende-gabbro. Near the foundry on Stone run, Cecil county, Maryland.

II. Quartz-biotite hornblende-gabbro. Near Porters bridge, Octoraro creek, Cecil county, Maryland.

III. Gabbro from the neighborhood of Radnor and Bryn Mawr. Analysis made by W. F. Hillebrand from three specimens representing three localities.

IV. Pyroxenite (Websterite). Oakwood, Cecil county, Maryland.

V. Norite. Near McKinseys mill, Cecil county, Maryland.

VI. Hornblende-gabbro. Stone run, seven-eighths of a mile northwest of Rising Sun.

Analyses II–VI were made by W. F. Hillebrand for Dr A. G. Leonard. Journal of American Geology, volume xxviii, pages 170-171.

Numbers I and II fall into class II, order 4, rang 4, and subrang 3. This means that the salic constituents are dominant over the femic constituents. Of the salic constituents feldspar is dominant over quartz, and lime-soda feldspar with dominant lime molecule is the prevailing feldspar.

Of the femic constituents the silicates are predominant and premirlic.

The structure of these rock species is the hypautomorphic granular; the abnormative minerals are biotite and hornblende in approximately the proportion of 1:2. These two species are therefore biotite-hornblende-grano-bandoses.

Number III falls into class II, order 5, rang 4, subrang 3, and is a dosalane hessose.

As in the case of the bandose, the salic constituents are dominant and femic constituents subordinate. Of the salic constituents feldspar predominates to an extreme degree, a departure from the bandose type, and lime-soda feldspar with dominant lime is the prevailing feldspar. Augite is the only abnormative mineral among the essential constituents of the rock. This is frequently present in notable amount and then plays the role of a critical mineral. The structure of the rock is hypautomorphic granular, and it may therefore be called an augitic grano-hessose.

Number IV is a diallagic-grano-cecilose (class V, order 1, rang 1, section 2, subrang 2)—that is, the rock is extremely rich in femic silicates, which are permirlic, permiric, and domagnesic in character. The salic constituents in this species are negligible.

Number V is a grano-kedabekose (class III, order 5, rang 5, subrang 3). The absence of mineral prefix in the name indicates that the rock contains no abnormative minerals. Salic and femic constituents are present in about equal proportions; of the salic constituents feldspar, and that a lime-soda feldspar, is dominant.

Number VI approaches I and II closely, and differs from them only in being percalcic. It is a biotite-hornblende-grano-corsose (class II, order 5, rang 5, subrang 3).

Among the gabbroitic intrusives there are then four dosalanes, one salfemane, and one perfemane. The dofemanes are doubtless represented by some of the peridotites of which analyses have not been secured. The granitic intrusive represents the persalanes as well as the dosalanes.

All of the five classes of igneous rocks are thus represented among the intrusives of the Pennsylvania Piedmont. With the exception of the non-feldspathic species (IV), the intrusives are either dofelic or perfelic. They are all, moreover, either docalcic or percalcic and presodic. While differentiation has given rise to representatives of many classes, the species show distinct magmatic relationship.

The intrusives of the Pennsylvania Piedmont are obviously part of a zone of docalcic or percalcic igneous types, a zone which, as pointed out by Doctor Washington, extends parallel to the Atlantic coast and lies west of a zone of dosodic to persodic igneous rocks.

SERPENTINES (META-PYROXENITE, META-PERIDOTITE, AND OTHER ALTERATION PRODUCTS)

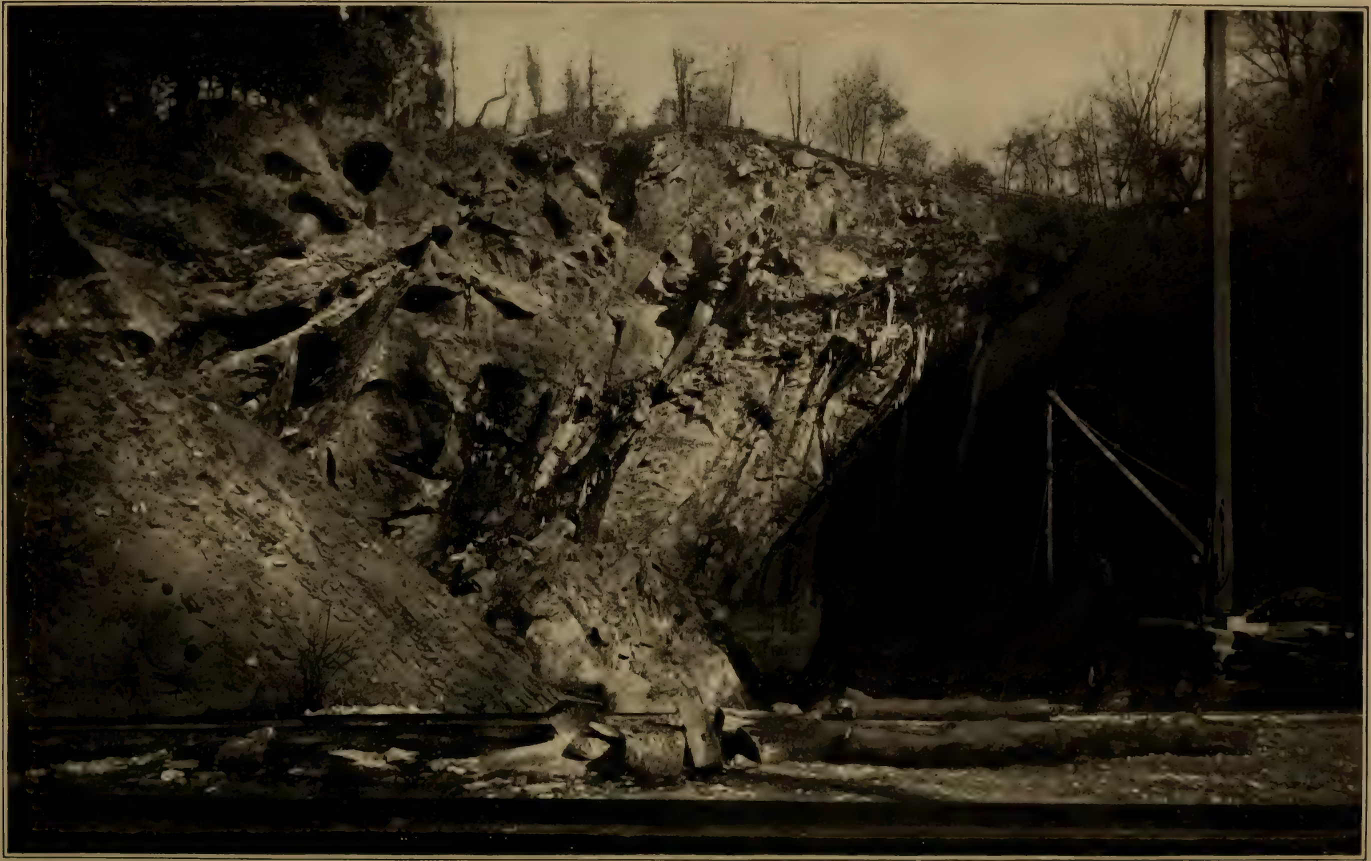
Distribution.—More or less intimately associated with the Atlantic belt of gabbro are altered pyroxenites and peridotites or meta-pyroxenites and meta-peridotites. These are the serpentines and related rocks. Serpentines of such origin are found in the Piedmont belt of North Carolina, Virginia, Maryland, Delaware, Pennsylvania, and New York states.

In the Philadelphia district there are four belts of interrupted lenticular exposures of serpentine and closely related rock types trending northeast and southwest. Two of these belts are on the southeast flank of the gabbro; one belt lies within the gabbro area and the fourth belt lies on the northwest flank of the gabbro. All of these belts continue southwestward into Delaware and Maryland.

Serpentine country, even though of so limited an area as is the case in the Philadelphia district, possesses certain marked and characteristic features. The areas underlain by serpentine stand out in relief as low ridges. The rock, though very soft, is exceedingly stable chemically, and hence weathering leaves it in relief. For the same reason the rock lies close to the surface of the ground, with many outcrops. In the less altered peridotites the material weathers in huge boulders, which strew the ground. Where the peridotite has been completely altered to serpentine the surface of the ground is covered with flat fragments broken along joint planes. The soil is thin and, like the rock, of a light green color. On relatively low land, where the soil possesses greater depth, it is of a deep-red color, due to the oxidation of the iron silicate.

Serpentine soil, because of its thinness and because of the magnesia which it contains, is not a fertile soil, and vegetation on serpentine areas is therefore scanty and of a peculiar character. The moss pink (phlox subulata) covers the ground in such profusion as to locally give the name Pink hill to some of the serpentine ridges. Cedars, scrub-oak, and cat-brier are very characteristic of the serpentine country, which usually presents a wild and barren aspect.

Character.—Of the four dikes the most southeasterly, which extends from Bryn Mawr to Chestnut hill, lies wholly in the Wissahickon mica-gneiss, but is presumably an offset from the main mass. Both the field and petrographic characters of this formation are those of an igneous



LAFAYETTE SOAPSTONE QUARRY

Montgomery county, Pennsylvania. Photographed by E. B. Harden

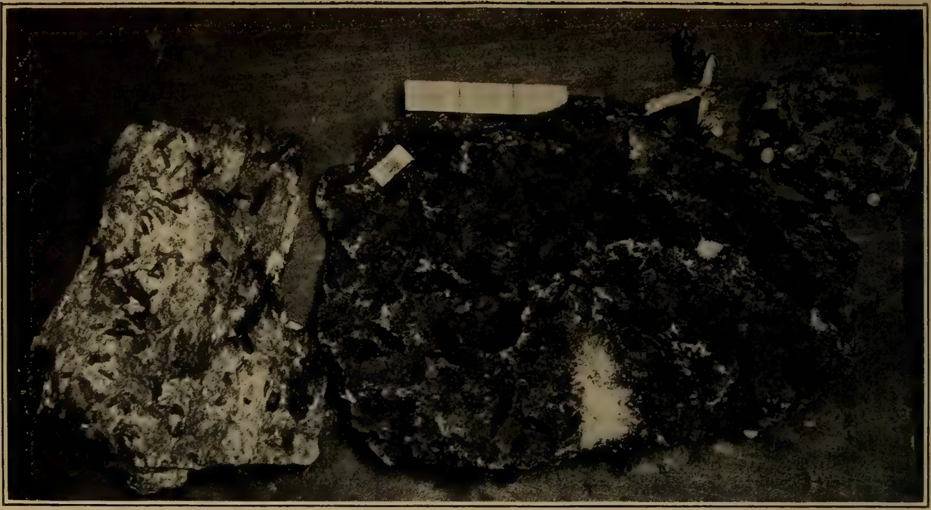


Figure 1.—Weathered Olivine in Steatite, Mill Creek, near Black Rock Quarry

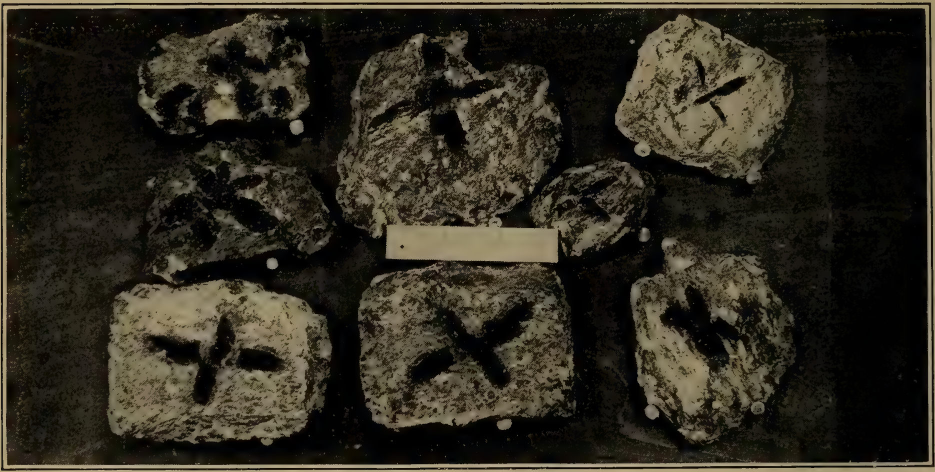


Figure 2.—Olivine Crystals in Steatite, Lafayette Quarry

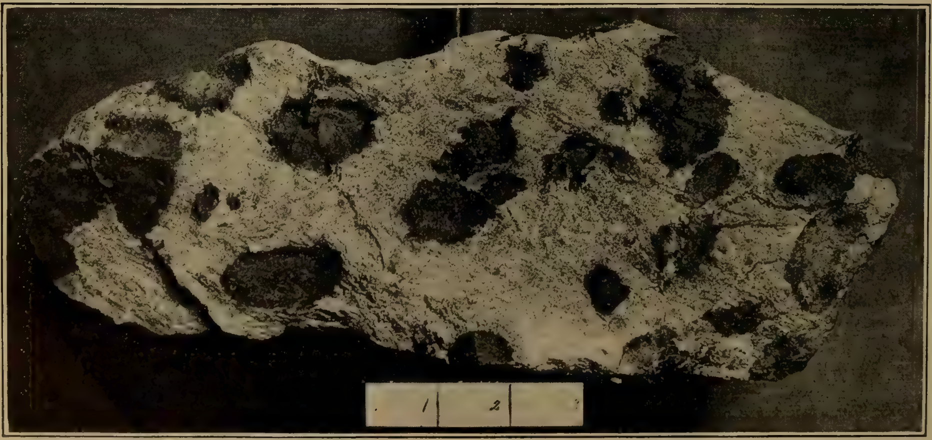


Figure 3.—Serpentinized Olivine in Steatite

SPECIMENS OF STEATITE FROM MONTGOMERY COUNTY, PENNSYLVANIA

From the Theodore D. Rand collection, Bryn Mawr College. Photographs by J. Volney Lewis intrusive. The interrupted character of the exposures, the variation in width of the belt, the massive nature of the rock, the contact phenomena, and the displacement of the mica-gneiss which have accompanied its intrusion are field evidences of an intrusive origin. Petrographically the rock shows alteration from the igneous type peridotite, an olivine-pyroxenite rock. It is in general characterized by the remains of olivine crystals, which are now largely altered to serpentine, by serpentine, which is often the chief constituent of the rock, by steatite (talc), which is an alteration product both of the original pyroxenic constituent and of the serpentine, and by calcite, quartz, and the iron oxides. The three last-named constituents not only occur in subordinate amount with serpentine as by-products of serpentinization, but as the final products of alteration they may constitute the entire rock mass. Breunnerite is also sometimes present as a by-product.

Locally the rock varies greatly. In some localities, notably near Lafayette, on both sides of the Schuylkill, it is a fairly pure, gray-green steatite (soapstone) (see plate 60), in others (near Mill creek) it is a massive blue-green serpentine or a reddish-yellow silicious rock, and in still others ("Black Rock quarry") the original rock type can still be traced. In this case dark-green serpentized olivine crystals mottle the light-gray steatite which forms the body of the rock (see figure 3, plate 61). Penetration twins of olivine, producing cross and stellate forms, have been found in this dike (see plate 61, figures 1 and 2). The formation is penetrated by a network of joints, and on the joint plane a blue-green opaline serpentine is sometimes deposited.

The second dike, upon the southeast flank of the gabbro mass, extends from the east bank of the Schuylkill to 2 miles southwest of Chester creek. It widens southward, reaching a maximum width of 1⅝ miles. There are numerous sporadic outcrops southeast of the main areas.

As in the case of the other dike, contact metamorphism has affected the surrounding rock. The mica-gneiss has altered to an actinolite-schist or to a spangled muscovite-schist or has become excessively garnetiferous. Petrographically the rock shows alteration from an original type which differed from that of the first dike in the possession of a larger amount of pyroxene and a smaller amount of olivine. This original rock type seems to have been a pyroxenite in which enstatite was the prevailing pyroxene. Associated with the serpentine are enstatite, tremolite, and anthophyllite in abundant development. The usual accessory constituents are present.

The third dike shows few exposures. The most conspicuous of them is located southeast of Edgemont. Here the rock lies piled up in picturesque masses, which have won for the locality the name of Castle rock (see plate 62). Serpentinization and steatitization are not far advanced in the main mass of Castle rock, which still shows the character of the original type, an augite-enstatite rock or pyroxenite. Associated with this pyroxenite is a pure green serpentine.

The serpentine of the fourth or most northwesterly intrusive extends with sporadic outcrops from the Schuylkill river southwestward. South of Paoli it expands into a considerable area, which is continuous to West Chester and has a sporadic extension to the state line and into Maryland.* The rock of this belt is chiefly a massive dark-green or a light-green granular serpentine. Fibrous serpentine is associated with it; also talc, quartz, magnetite, and limonite. The microscopic structure of the serpentine indicates that the original rock type was olivinitic—that is, a peridotite.

The genetic relationship of the serpentine (meta-pyroxenite and meta-peridotite) to the gabbro is to be seen in the petrographic character of the original types and in the field relations which it sustains to the gabbro. The first shows it to be a differentiation product of the gabbro magma; the second shows it to be either peripheral in character or a subsequent intrusive in spaces left by the contraction of the cooling gabbro magma.

The areas which have been mapped as serpentine country are by no means underlain by serpentine exclusively nor even by rocks in which serpentine is the predominating constituent. In some localities the serpentine has been completely removed and only silicious ironstones or "honeycomb rock" remains. In other localities serpentine is scarcely developed, and pyroxenite or peridotite are the underlying materials. In still other localities talc, anthophyllite, or chlorite are the prevailing alteration products, producing soapstone, an anthophyllite rock, or a chlorite schist. An occurrence on the tributary to Green creek, 1¼ miles southwest of Chelsea, is a pure anthophyllite-steatite rock, in which the former mineral occurs in large crystals. A great variety of minerals, in addition to or replacing serpentine, may develop from the alteration of basic igneous rocks. Talc, asbestos, anthophyllite, tremolite, hornblende, actinolite, epidote, chlorite, clinochlore, vermiculite, pectolite, magnetite, hematite, limonite, calcite, breunnerite, magnesite, quartz, especially drusy quartz, chalcedony, opal, chromite, and corundum have been found associated with the serpentine of the Pennsylvania Piedmont district.

META-GABBRO

Distribution.—Penetrating the Baltimore gneiss and the Wissahickon mica-gneiss are numerous dikes of basic igneous material. In many

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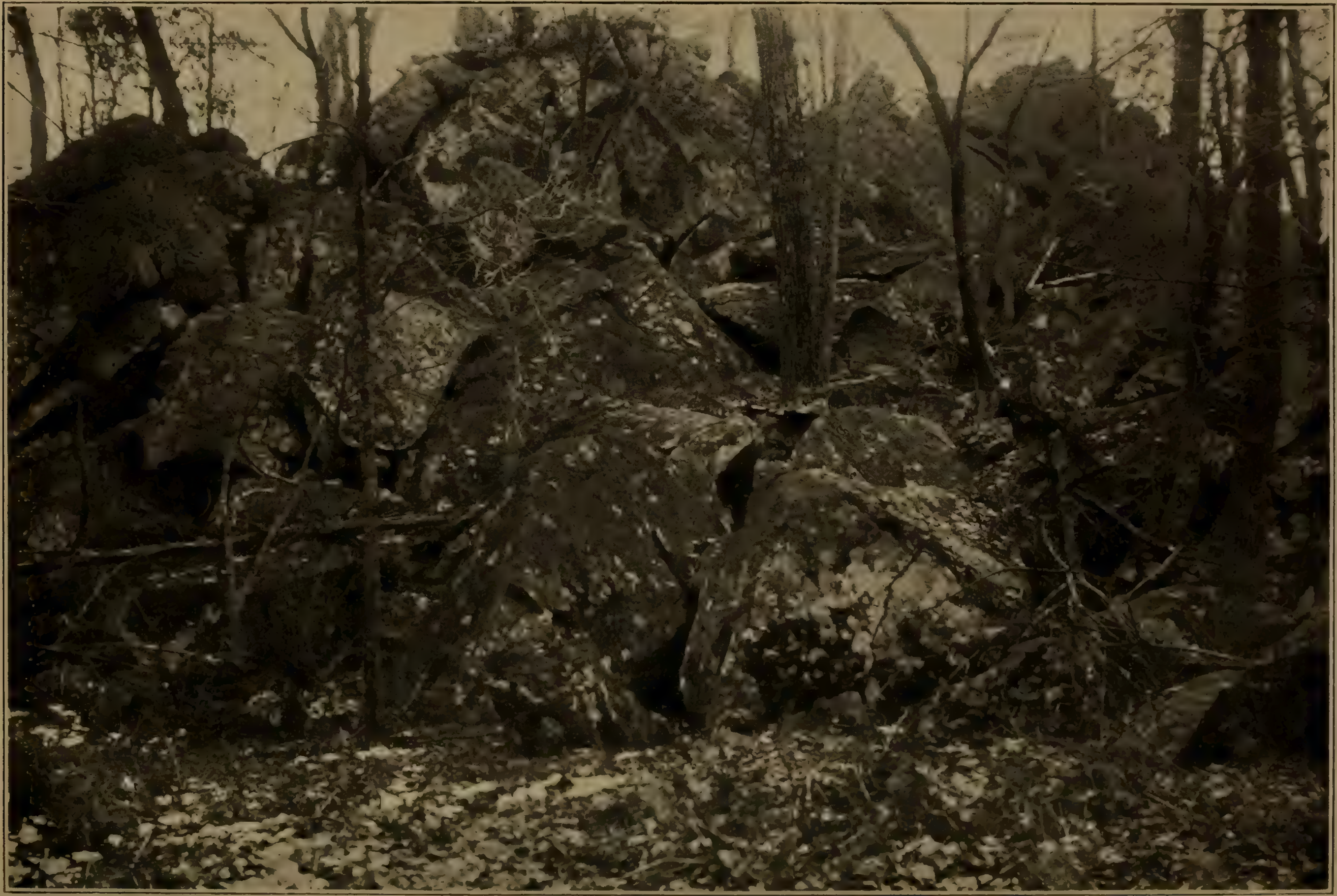
*For the geology and petrography of the "State Line" serpentines, as the serpentines of the extreme southern portion of this belt are designated, see Bascom, op. cit., pp. 93–94, 134–135.



CASTLE ROCK—A PYROXENITE DIKE

Delaware county, Pennsylvania

cases they are distinctly connected with the great gabbro intrusive, and presumably there is connection when it is not evident.

Such dikes occur 1½ miles south of Ithan on Ithan creek, one-half mile north of Ithan, one-half mile southeast of Villa Nova, in the Schuylkill section near Spring Mill, one-half mile north of Bryn Mawr station, on Crum creek in Willistown township, parallel to Crum creek in the neighborhood of Swarthmore, on Chester creek near Ridgewater, on Rocky run in Middletown township, at Edgemont and west of Edgemont in Edgemont township, at Valley Falls station on the Pennypack creek, near Vereeville on the same creek, at Ogontz, and at other localities.

Character.—An analysis by W. F. Hillebrand of a dike of meta-gabbro occurring 1 mile north of the Bryn Mawr station is as follows:

Analysis of meta-gabbro dike, Roberts road, Bryn Mawr

SiO_2	48.68	ZrO_2	Not estimated.
Al_2O_3	14.39	P_2O_5	0.29
Fe_2O_3	4.00	Cl	Not estimated.
FeO	10.09	T	Not estimated.
MgO	6.32	S	Trace.
CaO	9.23	Cr_2O_3	None.
Na_2O	2.31	NiO	Trace.
K_2O	0.47	MnO	0.22
H_2O+	2.03	BaO	Faint trace.
H_2O-	0.46	SrO	None.
CO_2	None.	Li_2O	Trace ?
TiO_2	1.69		100.18

Norm

Quartz	2.82	Magnetite	5.80
Orthoclase	2.78	Ilmenite	3.19
Albite	19.39	Apatite	0.67
Anorthite	27.52	H_2O	2.49
Diopside	13.67		
Hypersthene	21.78		100.11

The rock falls into class III, order 5, rang 4, subrang 3—that is, it is a hornblende-grano-auvergnose.

Like the gabbro mass to which it is probably genetically related, it is perfelic, docalcic, and presodic, though it is slightly more basic, the femic constituents being equal to the salic.

HORNBLENDE-GNEISS

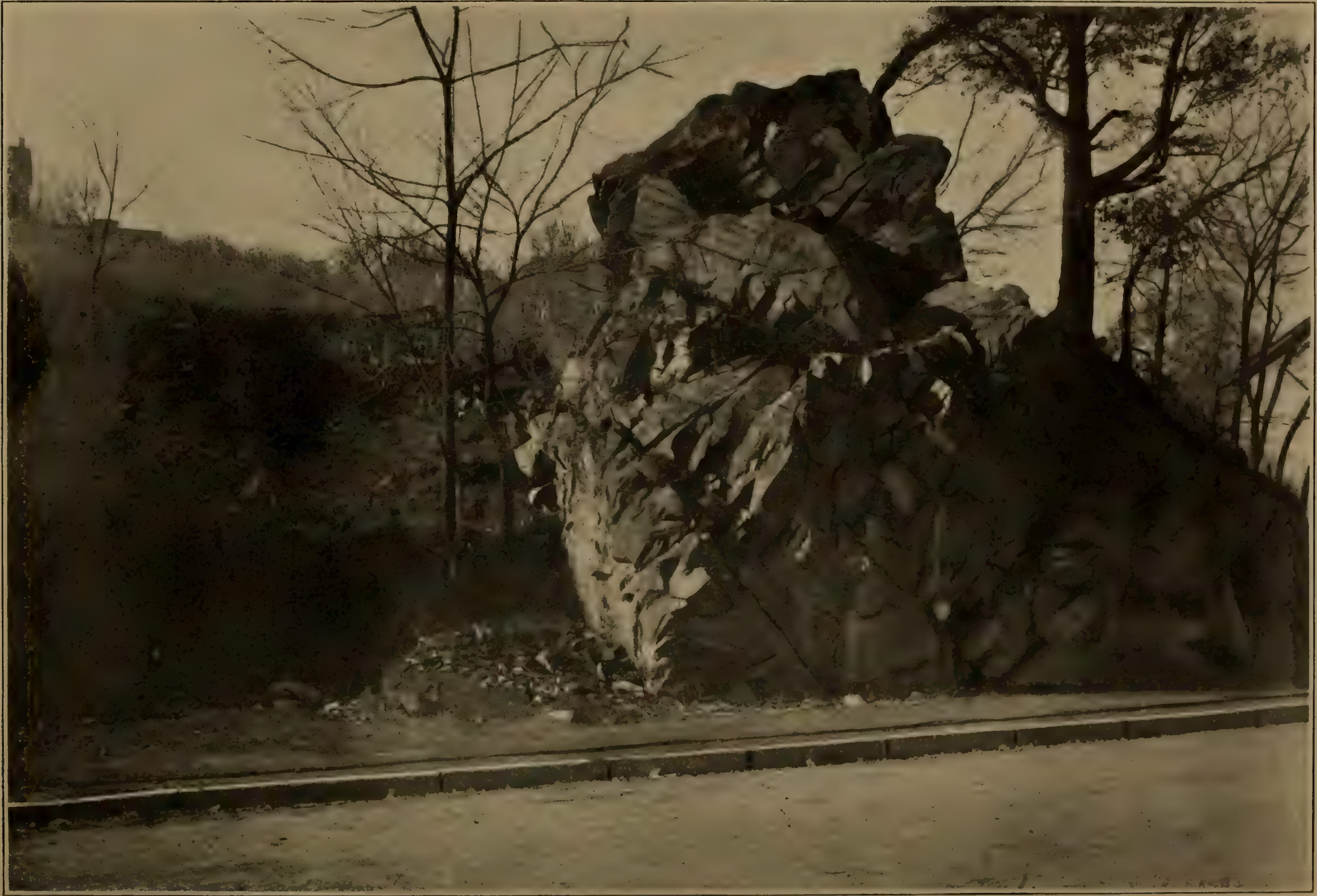
In addition to the basic dikes above described there occurs a larger body of hornblende-gneiss whose areal distribution is concealed by a covering of younger materials. Quarries on the outskirts of Frankford;

near Chelten avenue, Germantown; an exposure on the Pennypack creek, north of Holmesburg, reveal the character of the material. It is also penetrated by the shafts and tunnel of the Torresdale filtration plant. The contact of the hornblende-gneiss and the Wissahickon mica-gneiss was seen in this tunnel. The contact is diagonal to the structure planes of the mica-gneiss, and apophyses from the hornblende-gneiss extend into the mica-gneiss. The character of this contact and the constitution of the rock indicate an intrusive, igneous origin. The rock is medium-grained and dark colored, owing to the prevalence of hornblende. This constituent is dark green and is arranged with the longest axes parallel, thus producing the gneissoid structure. The other constituents are quartz, orthoclase, microcline, oligoclase, biotite, titanite, and apatite. The structure is granulitic and gneissoid. Owing to the excess of hornblende, the rock is darker colored than the granitic intrusive on the west side of the Schuylkill river. It is otherwise not unlike it, and may be genetically related to the granite. The stone, which is extensively quarried at Frankford, has been used for building purposes and for bridge abutments.

DIABASE

The intrusion of igneous material, which characterized the Triassic period and which manifests itself to the north in the great diabase masses of mount Holyoke, mount Tom, the Palisades, and First and Second mountains in New Jersey, shows itself in this district in a few dikes not exceeding 100 feet in width. The chief of these dikes has been known as the Conshohocken dike because of a prominent outcrop of it in that town. This exposure is figured in plate 63. It has been traced continuously from Lafayette hill to the gulf, and thence intermittently into Maryland. It possesses a width of about 30 feet.

The rock exhibits a very uniform character. The boulders are readily recognized by a rusty-yellow oxidized coat and a greenish-gray color on the fresh surface of the characteristically conchoidal fracture. The rock is a comparatively fresh, medium-grained, typical diabase, with plagioclase and pyroxene in about equal amounts as primary essential constituents and ilmenite and apatite as accessory constituents. The secondary constituents are chlorite, scanty biotite, quartz, calcite, and epidote. The plagioclase is labradorite-bytownite, which forms a network of automorphic lath-shaped crystals. The pyroxene is the aluminous monoclinic variety, augite. It is zenomorphic and fills the interstices of the feldspar network. Another diabase dike 80 to 100 feet wide extends northeast and southwest in the neighborhood of Dreshertown, Jarrettown, and Warminster. It is exposed in a cut on the Pennsylva-



DIABASE DIKE

West Conshohocken, Montgomery county, Pennsylvania

nia railroad north of Camp hill. Some stray boulders of the rock show on Camp hill, but the dike can not be traced farther into the Paleozoics. The rock is of the same petrographic type as the Conshohocken dike and possesses like structure and constituents. A third dike of considerable width strikes northeast from Mortonville toward Downingtown.

A very fine-grained diabase dike 8 to 10 centimeters in width and somewhat more basic in composition traverses the Ordovician schists at Williamsons point, on the Susquehanna river. All these dikes are of Triassic age.

Analyses of material from two diabase dikes

	I.	II.
SiO_2	51.56	50.79
Al_2O_3	17.38	14.19
Fe_2O_3	6.57	3.84
FeO	3.85	7.44
MgO	3.42	7.88
CaO	10.19	9.75
Na_2O	2.19	1.89
K_2O	1.46	0.95
Loss	2.15	1.95
TiO_2	1.63	0.70
PO_4	0.13	0.15
Li_2O	Trace.	Mno. 0.48
	100.53	100.01

Analysis I is of a diabase dike, West Conshohocken, Montgomery county, Pennsylvania.

Analysis II is of a diabase dike, Williamsons point, on the Susquehanna river,* Lancaster county, Pennsylvania.

Norms

	I.		II.
Quartz	13.44		3.36
Orthoclase	8.90		6.12
Albite	12.56		16.24
Anorthite	36.42		26.97
Enstatite	8.50	Hypersthene	21.79
Wollastonite	5.57	Diopside	16.65
Apatite	0.34		0.34
Ilmenite	3.04		1.37
Magnetite	7.89		5.57
Hematite	1.12		....
H_2O	2.15		1.95
	99.93		100.36

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*Analyses made by Dr F. A. Genth, Jr., Second Geological Survey of Pennsylvania, vols. ccc, p. 275, and c^6, p. 134.

The Conshohocken diabase therefore falls into class II, order 4, rang 4, subrang 3. This indicates close similarity to gabbro, differing chiefly in the relation of the feldspar of the other salic constituents.

Feldspar is dominant over quartz, but not to an extreme degree. The anorthite molecule is dominant over the alkali feldspars and soda is the dominant alkali. Augite is a critical mineral, the structure is megophitic, and the name augite-ophito-bandose.

The diabase of Williamson's point falls into class III, order 5, rang 4, subrang 3. It is an augite-ophitic-auvergnose. This means that the salic and femic constituents are present in about equal amounts; that of the salic constituents feldspar predominates; that among the feldspars the anorthite molecule dominates, while of the alkalies soda dominates. Augite is an abnormative mineral and the structure is micro-ophitic.

PEGMATITES

In the southwestern portion of the belt there occur sporadically numerous pegmatite dikes which have considerable width, can be traced for long distances, and possess a commercial value.

Where they are favorably situated with reference to drainage lines the acid feldspar in which they abound is completely kaolinized and furnishes large kaolin plants with clay. Elsewhere the fresh feldspar is utilized for dental purposes and for pottery.

GEOLOGIC HISTORY OF THE PIEDMONT DISTRICT OF PENNSYLVANIA

The sedimentary series of the Pennsylvania Piedmont indicate that a comparatively limited land mass existed on the eastern border of the continental plateau in late pre-Cambrian time; that during Cambro-Ordovician time there were deposited in an encroaching sea upon the western border of this land mass arenaceous, calcareous, and argillaceous sediments successively. There is no record in the Pennsylvania Piedmont of further sedimentation during Paleozoic time. It is not probable, however, that the subsequent land movements immediately followed on the deposits of argillaceous material, and that sedimentation in this district closed.

The amount of material deposited in Paleozoic time, which has disappeared through subsequent erosion, is not known, but was presumably of considerable extent. Beginning, perhaps, at the close of Ordovician time and continuing until the close of Paleozoic time, there were earth movements along the Atlantic border which resulted in the uplifting, folding, and recrystallization of these sediments.

The pre-Cambrian arkose, by crystallization and metasomation, was converted into a gneiss. Induration and crystallization, a mass movement and a molecular movement in response to pressure, have converted the Cambrian beach deposit into a conglomerate schist and a quartzite. Where the sand was originally impure metasomation has been an accessory process, and the products, a sericitic quartz-schist.

Crystallization and an interchange through the agency of ocean water of calcium and magnesium carbonates have been the processes chiefly active in converting the calcareous precipitates and sediments into marble or crystalline limestone.

The impurities present have crystallized into silicates, such as phlogopite (chiefly), tremolite, and diopside, and all evidence of organisms which may in some degree have assisted in the original formation of the rock is lost.

Crystallization and metasomation have been the chief processes concerned in the production of the Wissahickon mica-schist and mica-gneiss from the arcosic and argillaceous material. Muscovite and quartz have developed from the feldspathic material present and a schist produced, or the feldspathic material has recrystallized as feldspar and the ferromagnesian material present in the sediment as biotite, and the resulting rock type is a mica-gneiss. Both injection and impregnation have locally taken part in the development of the Wissahickon mica-gneiss, producing a banding which very perfectly simulates gneissic banding. The fact that the new minerals which have crystallized from the impurities of the sediments are exclusively minerals, which, by the parallel orientation of their longer axes normal to the direction of compression diminish the horizontal dimension of the formation, shows that their development like the folding was in response to pressure and was a means of relieving strain. The intensity of the pressure is further indicated by the fact that muscovite and biotite are developed in such excess to the almost complete exclusion of hornblende and chlorite. The development of new minerals has thus been accompanied by the development of new structures, namely, schistosity and gneissic banding.

The flattening and rotation of the original minerals of the sediments, such as quartz or feldspar, as well as parallel orientation, described above, of the new minerals, takes part in the production of these structures. This deformation, which results in schistosity, is microscopic as well as megascopic. A strained molecular condition, giving rise to undulatory extinction, peripheral granulation, complete granulation, and rotation of the grains are stages in the process.

Granulation is not a feature of the Piedmont sedimentary formations.

The presence of water, which characterizes them as sediments, is favorable to crystallization rather than to granulation and rotation. The intensity of the pressure also favors crystallization rather than granulation.

The earth movements, which metamorphosed the sedimentary series, were accompanied by the intrusion into the rising crust of the earth of great igneous masses which further metamorphosed the squeezed and crushed sediments and which consolidated into granite, gabbro, pyroxenite, and peridotite. If there were any volcanic outbursts at this time, all record of them has been removed by erosion.

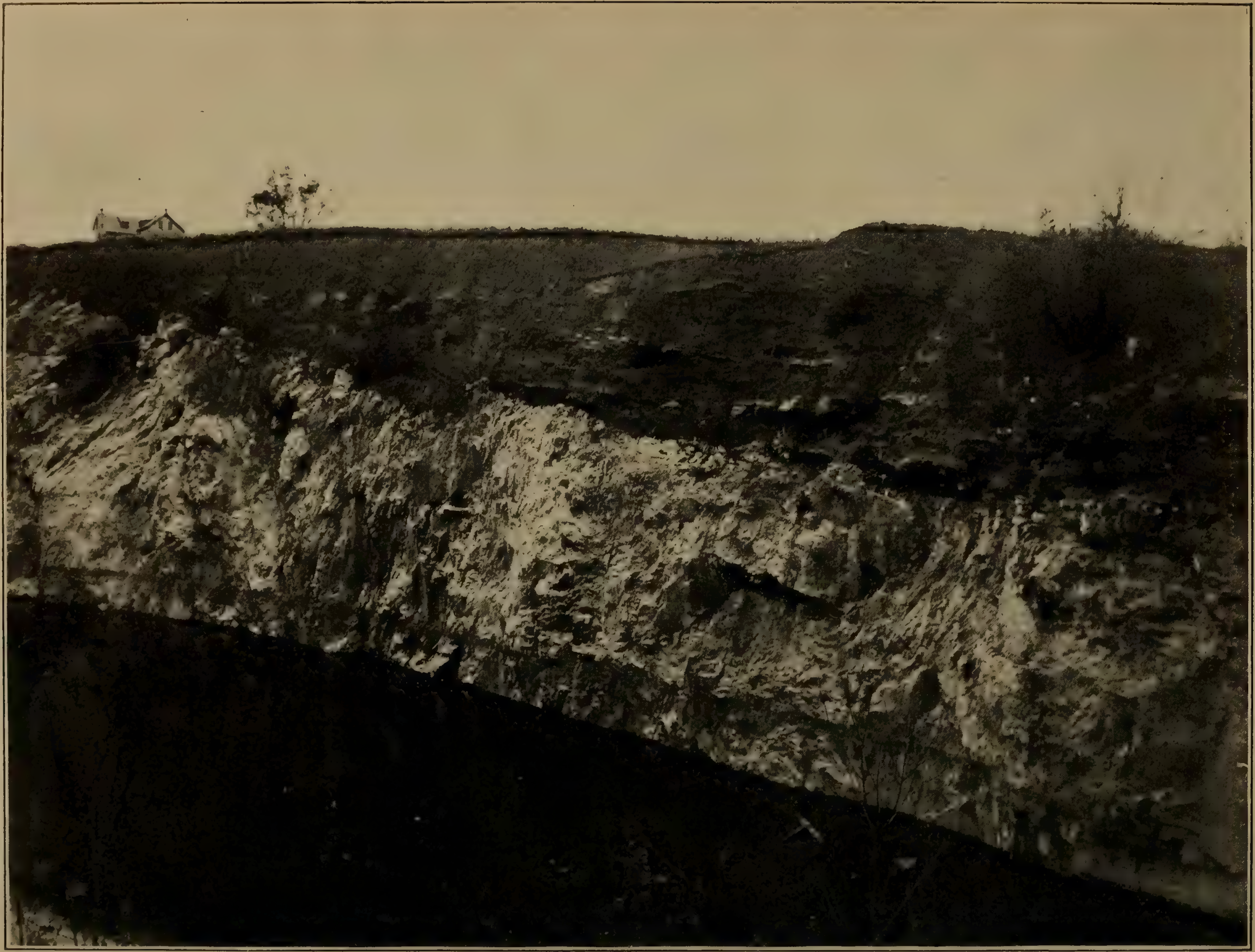
The igneous material that is now exposed consolidated before reaching the surface. Pressure was a much less active agent in the further crystallization and metasomatism which accompanied the intrusion of these igneous bodies. The crystallization was therefore of a more granular character and the new minerals are not those which possess less bulk than the original minerals. Under these conditions garnet, tourmaline, staurolite, andalusite, hornblende, and chlorite have developed.

These minerals reach a size which renders them conspicuous to the naked eye. When developed in the neighborhood of igneous bodies they take part in the parallel orientation common to the other constituents of the gneiss.

Their longer axes or their prominent cleavages may be transverse to the schistosity of the containing rock. This fact, the relatively larger dimensions of the crystals, and their granular form give them a porphyritic character and show that their formation must have been subsequent to the period of greatest pressure.

With the elevation and accompanying metamorphism, the character of which has been indicated, of these simple sediments began the history of the Piedmont land surface.

It was stated on page 291 that the present form of the plateau is not a constructional form; that the rock structure is discordant with the surface configuration. If the comparatively slight depressions made by the present streams were filled in, a perfectly level plain would result, sloping seaward. If, on the other hand, the arches and troughs of the original anticlines and synclines were restored, a region of lofty mountains and deep valleys would be developed. These two strikingly unlike topographies are separated by a long and more or less complex erosion history. It is to be doubted whether the perfect constructional form ever existed, but a greater height of land than exists at present must have characterized this region during some portion of Paleozoic time. This height of land was so far reduced at the opening of Triassic time that it



CHESTER VALLEY LIMESTONE WITH UNCONFORMABLE COVER OF TRIASSIC SHALES

Port Kennedy, Montgomery county, Pennsylvania was upon a comparatively level and a deeply eroded crystalline floor that the materials of the Trias were laid down (see plate 64).

There is independent proof that the main lines of drainage flowed westward during pre-Cretaceous time, and the later sediments of the Paleozoic series must, in some measure, represent the material denuded from this belt of high land.

During Triassic time the portion of the plateau not submerged beneath the Triassic estuary, which occupied the central portion of the district, drained northwestward into this estuary and furnished material to the sediments accumulating there.

Post-Triassic elevation inaugurated a period of erosion which must have continued during Jurassic and into early Cretaceous time. It was during this period that a nearly featureless plain sloping seaward was formed. The fact of peneplanation may be observed in the level sky-lines of the ridges and hills, and it explains the discordance between surface configuration and underground structure. The time of peneplanation is fixed by the age of the deposits borne on its surface. The oldest deposits on this peneplain are the Patapsco and the Raritan, belonging to Lower Cretaceous time. . The peneplain also carries deposits of Upper Cretaceous, Tertiary, and Quaternary time. These deposits indicate that the time of the peneplanation was Jurassic, and that it was terminated by submergence of the land. This submergence was not due to a single crustal movement, but to a complex interrupted series of movements.

First there was subsidence with tilting, which perhaps produced estuaries bordering the sea and extending inland roughly parallel to the present sea border. In these estuaries were deposited the clays and gravels of the Patapsco formation. An elevation followed which brought the Piedmont district above the sea, and the erosion, which succeeded this elevation, removed the Patapsco deposits except from the deepest portions of the inland estuary.

Following the erosion interval was a second subsidence and the renewal of estuaries, in which Raritan deposits were laid down. The uplift that followed was more marked than the preceding, and the plateau remained above water during a long period of time, in which a great thickness of Raritan was removed. The third post-Triassic subsidence, which followed this erosion interval, lasted during all Upper Cretaceous time, was more extended than any of the preceding, and was oscillatory in character. The adjoining land must have been low, so that the streams furnished only fine sand deposits. Following on Cretaceous time was an elevation and an erosion interval of long duration, during which portions of the Coastal plain was intermittently beneath and above water. The plateau remained above water continuously until Lafayette time, when all the Coastal plain and part of the Piedmont district was brought beneath the sea by tilting, which elevated the northern half of the plateau. The velocity of the streams was accelerated so that they were able, for the first time since the Raritan epoch, to carry to the sea coarse as well as fine gravel. It was at this time that the formation known as the "Bryn Mawr gravel" was spread on the plateau. The uplift which followed this tilting inaugurated a drainage which could not have been very unlike the present. The lower courses of the Schuylkill and the Delaware became established along the present lines and the development of the present topography began.

Following this uplift there was a subsidence of the extreme eastern portion of the plateau. A stationary position of the shoreline is indicated by the escarpment crossing the plateau diagonally from southwest to northeast, mentioned on page 291. The 180-foot contour approximately outlines the escarpment which extends from Gordon heights northeast to Somerton. It can be easily located by the present boundaries of the Sunderland deposits, though erosion has removed this material from the near neighborhood of the former shoreline. In the vicinity of Somerton it is a well defined escarpment, from which the plain of submarine erosion to the south may be overlooked.

Only the extreme eastern portion of the plateau was affected by the following crustal movements of uplift, erosion, and subsidence which are recorded in the deposits of the Wicomico and Talbot formations, and which affected the entire surface of the Coastal plain.

Since Talbot time both the Piedmont plateau and the Coastal plain have been continuously above water, and the drainage of the plateau has assumed its present form.

The Jurassic peneplain now stands at a height sufficient for the establishment of a drainage actively eroding its surface.

The cover of Cretaceous, Tertiary, and Quaternary formations have been so far removed as to lay bare large areas of the crystalline peneplaned floor in which the streams are again cutting their valleys. The peneplain has thus by elevation become a plateau and by the renewal of erosion a dissected plateau.

That the main streams maintain courses which are independent of the lithologic character and structure of the underlying rock is due to the presence of the cover of Cretaceous, Tertiary. and Quaternary materials which, existing at the time of the development of the drainage, masked the pre-Paleozoic and Paleozoic series beneath it. The drainage superimposed upon this cover became too well established in courses consequent upon the slope of the plateau and independent of the concealed rock floor to alter them when subsequently the rock floor was discovered.

The Wissahickon and the Schuylkill, crossing the easily eroded limestone belt and cutting gorges in hard gneisses, are examples of superimposed streams. The peculiar courses of Gulf and Valley creeks, on the other hand, are due rather to stream robbery.

Each of these streams originally pursued direct northeast courses to the Schuylkill. Their headwaters were captured by tributry streams to the Schuylkill possessing higher gradients. Valley and Gulf creeks therefore turn nearly at right angles to their former courses and pursue northwest courses. The beheaded remnants of these streams are Trout and Mechanicsville creeks.

The secondary tributaries do not show the characters of superimposed streams, but are adjusted to the constitution of their rock bed. This fact and differential weathering explain the minor diversities of topography which have been noted in that portion of the plateau in which the Paleozoic and pre-Paleozoic series are uncovered.

Résumé

The crystalline formations of the Piedmont district of Pennsylvania are a pre-Cambrian gneiss, a Cambrian quartz-schist, a Cambro-Ordovician marble, and an Ordovician mica-gneiss and mica-schist, together with intrusive granitic and gabbroitic igneous rocks.

The dynamic forces which have developed these formations from simple sediments have folded them in anticlinoria and synclinoria, with major axes striking northeast-southwest and minor axes transverse to the major axes.

Following this folding, which was accompanied by thrust faulting, occurred pre-Triassic erosion, succeeded by Triassic estuarine deposition.

The period of elevation which followed was marked by the production of the Jurassic peneplain, on which was subsequently spread the deposits of Cretaceous, Tertiary, and Quaternary time, separated by brief erosion intervals.

With the final elevation of the Jurassic peneplain began its dissection and the development of the present topography.

Addenda

Since this paper has been put in type a field conference has been conducted with Messrs A. Keith, G. O. Smith, and E. B. Mathews with a view to determining the age of the Wissahickon mica-gneiss. The results of this conference, while establishing the Ordovician age of the Wissahickon mica-schist, place in question the equivalence of the Wissahickon mica-gneiss and the Wissahickon mica-schist.

If the former formation should prove to be faulted on the latter formation with a low southeast hade, and if the apparent superior position of the Wissahickon mica gneiss on the Chester Valley limestone be due to overturned synclinal structure—a possibility which the writer recognizes—the Wissahickon mica-gneiss will be shown to be pre-Cambrian in age. Detailed work in areas not yet mapped will be necessary in order to establish the Ordovician or the pre-Cambrian age of the Wissahickon mica-gneiss.

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CORRELATION OF MARYLAND AND PENNSYLVANIA PIEDMONT FORMATIONS*

BY EDWARD BENNETT MATHEWS

(Read before the Society December 30, 1904)

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INTRODUCTION

The generalizations and conclusions presented in the present paper are based on the detailed work of the writer and his assistants on the Maryland Geological Survey, covering the territory from the Susquehanna river to longitude 76 degrees 50 minutes, with the exception of a small area in the immediate vicinity of Baltimore, and on the lines determined by the late Professor Williams, confirmed by a rather detailed reconnaissance by the author, on the territory west of this line to the area of the Frederick and West Washington sheets, where the work of Mr Keith, supplemented by reconnaissance work by the author, is used. The writer has also had access to the field notes, manuscript material, and microscopic sections of Professor Williams, which were prepared by him during his work on the United States Geological Survey. The conclusions reached from the information received from these various sources are, however, the work of the writer, who alone is responsible for them.

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During the course of the work in the Maryland area, extending over a period of ten or twelve years, there have been frequent conferences with Miss Bascom, who has been engaged in investigations in the Piedmont area, and the knowledge of the results there gained have been generously placed at the disposal of the writer at all times. The conclusions reached, independently in the Pennsylvania and Maryland areas, are found to be in practical accord, and it is the purpose of the present paper to show the harmony of interpretation in these two areas and to discuss the southward continuation of the various formations and structures described by Doctor Bascom in the preceding paper.

FORMATIONS OF THE PIEDMONT

LIST OF THE FORMATIONS

In a paper previously published by the author[*] it was shown that there are within the Maryland area six well defined sedimentary formations and numerous rocks intruded in them. The sedimentary formations are as follows:

Ordovician ?	Peachbottom slates.
	Cardiff quartz conglomerate
	Wissahickon mica-schist, including phyllite with intercolated limestone bands at the top.
Cambro-Ordovician (Shenandoah) ?	Cockeysville[†] marble.
Cambrian	Setters[†] quartzite.
Pre-Cambrian	Baltimore gneiss.

BALTIMORE GNEISS

The oldest formation in Maryland is the Baltimore gneiss, which occurs in several well defined areas in the eastern portion of the Piedmont between the Susquehanna and Potomac rivers. The easternmost of these Baltimore gneiss occurrences is within the area of Cecil county, east of the Susquehanna river, studied by Doctor Bascom, and extends from this point southwestward, widening to an area of 5 miles or more in breadth where it is overlain by Coastal Plain deposits. This formation is limited on either side by igneous rocks. An outlier a mile or less in width, extending for several miles southwestward from the Susquehanna river, probably represents a detached portion of this larger mass lying a little to the south.

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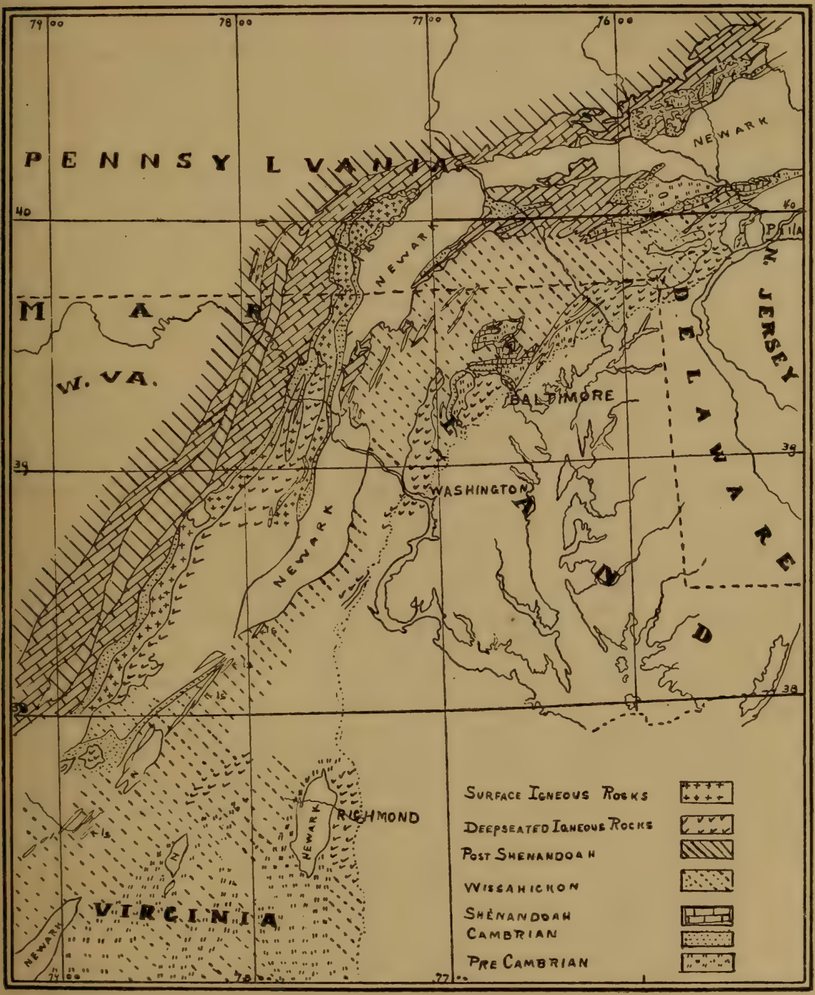
[*] The structure of the Piedmont plateau as shown in Maryland. Amer. Jour. Sci., 4th ser., vol. xvii, 1904, pp. 141–159.

[†] The terms Cockeysville and Setters are old terms employed by Williams, which are here used pending the final decision on names by the Committee on Formation Names of the U. S. Geological Survey. It is not thought that they represent any different horizons from the Chickies quartzite and Chester Valley limestone of the Philadelphia area.

The second occurrence* of Baltimore gneiss is found in an anticlinal dome, 15 miles long and 5 miles broad, lying on either side of the Northern Central railroad 10 miles south of the Mason and Dixon line and 20 miles north of Baltimore.



79 00
78 00
77 00
76 00
PENNSYLVANIA
NEWARK
40
MARYLAND
W. VA.
NEWARK
PHILA
N. JERSEY
DELAWARE
BALTIMORE
39
WASHINGTON
NEWARK
38
RICHMOND
NEWARK
VIRGINIA
NEWARK
79
78
77
Surface Igneous Rocks
Deepseated Igneous Rocks
Post Shenandoah
Wissahickon
Shenandoah
Cambrian
Pre Cambrian

FIGURE 1.—*Distribution of Formations in Maryland Piedmont and contiguous Areas.*

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* Detailed maps of the region north of Baltimore accompany the following paper by the author and Mr Miller.

Three smaller areas occur in the vicinity of Baltimore. Two of them are portions of anticlinal domes which are either completely enclosed by overlying sediments or cut off by faults and igneous rocks, while the third, underlying the northwestern part of Baltimore city, is entirely surrounded by gabbro and other igneous masses and is overlain in great measure by the Coastal Plain deposits.

Between Baltimore and Washington, along the boundary line between Montgomery and Prince George's counties, occurs another area of Baltimore gneiss, which up to the present has not been fully investigated by the author.

The rocks in each of these areas consist of highly crystalline gneisses composed of quartz, feldspar, and mica, with accessory minerals, which are so distributed as to produce well marked, gray banded gneisses, the individual bands of which vary from a fraction of an inch upward, the average thickness, however, being quite thin. Some of these beds are highly quartzose, resembling a micaceous quartzite; others are rich in biotite or hornblende, producing dark schists, which in a hand specimen are indistinguishable from metamorphosed igneous masses. Within the area of Baltimore gneiss are numerous small bodies of metamorphosed granites and more basic igneous rocks, which have been intruded into the gneiss and subsequently metamorphosed until they are practically indistinguishable from it. The differences in character can now and then be recognized, but it has not been found possible to carry the mapping of these small igneous intrusions from one exposure to another, and frequently they are so small that they could not be represented on maps of the scale (1:62,500) employed.

SETTERS QUARTZITE

The Setters quartzite occurs usually as a narrow rim on the flanks of the areas of Baltimore gneiss, but is not continuous or always present. Thus in the easternmost areas of Baltimore gneiss previously described no Setters quartzite was recognized. It was found, however, skirting the anticlinal dome of Baltimore gneiss along northern Baltimore county, where it occurs as a single band on the eastern end of the dome and as a series of somewhat parallel ridges on the northwestern slope of the anticline, where the contact between the underlying gneiss and the quartzite is near the present surface of the country. On the southern slopes of the anticlinorium the quartzite seems to be lacking along the western half, but is found in varying thickness along the eastern part of the anticline.

The quartzite also occurs in the smaller anticline about a granite mass in the vicinity of Warren, just south of the previously described anticlinal dome.

Quartzite from the typical ridge originally described by Professor Williams occurs as a continuous belt about the small anticlinal dome lying 10 miles northwest of Baltimore between the Northern Central and Western Maryland railroads. The formation here is of rather uniform thickness and stands at a steep, sometimes overturned, angle on the flanks of the gneiss. Across the valley of lake Roland is a similar, though less well defined, anticlinal arch of more complicated structure, along the sides of which may be seen the Setters quartzite, extending from the Northern Central railroad on the west to the eastward until it is cut off by overlying formations or igneous rocks.

The Baltimore area of gneiss is included entirely within the gabbro, and no quartzite is to be noted along its borders.

On the western side of the Baltimore area, extending southward through Howard county, may be found occasional exposures of Setters quartzite between the gneiss and the marble. The work in this area has not been completed, but it seems quite probable that the quartzite will be found developed as a more or less continuous stratum lying between the Baltimore gneiss on the east and the overlying marble on the west, as it has already been recognized in this position at many points.

The quartzite is a fine-grained, somewhat saccharoidal, thin-bedded rock of white or cream color in its typical development along Setters ridge. At this point the beds are usually separated by thin films of muscovite or sericite in small sparkling flakes. On the surface between the individual beds are black tourmalines, which have been more or less disturbed, as shown by the stretching which they have undergone. The Setters quartzite as a formation is, however, somewhat more variable than was at first supposed from the study of the original locality on the south side of Greenspring valley. Locally the rock may become very vitreous and massive, resembling some of the Huronian quartzites of the Lake Superior region. At other times the rock becomes more argillaceous, with a development of garnets, staurolite, and other accessory minerals. The development of such minerals causes the quartzite formation to simulate in lithologic character the overlying Wissahickon mica-schist, and at first occasioned considerable difficulty. It is now known, however, that the more quartzose layers may be intimately interbedded with the more micaceous and garnetiferous ones toward the center of the formation, and that the upper portion of the formation when well developed may be highly micaceous and garnetiferous.* The development of this micaceous phase of the Setters formation is especially marked along the valley at Stringtown and in the northeastern extension of the limestone valley at Cockeysville. A third instance of this character is found in the small anticline at Warren, especially near the mouth of Royston branch. In all of these instances the micaceous member of the quartzite is seen to *underlie* the marble and to overlie or to be interbedded with the more quartzose phases of the Setters formation. Moreover, the structure at the various points is such that the occurrence of this garnet mica-schist can not be explained as a faulted-in portion of the Wissahickon mica-schist overlying the marble, as was first supposed by the writer.

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* The presence of a somewhat sericitic quartzitic lower member and a more argillaceous overlying member is strikingly in accord with the characteristic Cambrian deposits of York county, Pennsylvania, and those of the Catoctin area described by Keith, as well as those of Balcony falls, Virginia, as described by Campbell. There is, however, more metamorphism with the development of metamorphic minerals in the rocks of the eastern Piedmont.

COCKEYSVILLE MARBLE

The exposures of Cockeysville marble found in the Maryland Piedmont may be included within an ellipsoidal area with a major diameter of 40 miles extending northeast and southwest from Harford county on the east to Montgomery county on the south and a minor diameter of about 10 miles. The areal distribution suggests that there was in Maryland a local basin of deposition, but there are few, if any, facts known confirming this suggestion. The maximum development of the Cockeysville marble is found in the synclinorium* lying between the anticlines of Baltimore gneiss and quartzite about 10 miles north of Baltimore city. It is here found underlying the Wassahickon mica-schist and overlying the quartzite, the various formations recurring at the surface through numerous foldings, the contact between the marble and the adjacent formations lying very close to the present surface of the country. Southwest from this larger area of Cockeysville marble the formation may be traced in four exposures along well defined valleys to the vicinity of Clarksville, in Howard county, with but little or no interruption, the formation occurring as part of a monoclinal fold to the westward or as the eastern side of the large synclinorium which will be discussed later. The details regarding the southwestern exposure of the Cockeysville marble are not all worked out, and it seems quite probable, from the facts at hand, that there is a fault striking northwest and southeast and extending southeastward to a point near Laurel. The marble occurring in these areas is in the majority of instances rich in magnesium and should be called a dolomite. This is particularly true at the type locality, Cockeysville, but there are frequent changes in the amount of magnesium present, and one often finds magnesium-free or magnesium-poor rocks in proximity to the dolomitic varieties. The changes in composition are sharp and generally easily recognized by the quarrymen, who are assisted by the fact that the dolomitic marble averages finer grained and richer in magnesium-mica than the better-burning, magnesium-poor rocks. Attempts have been made by acid tests in the field to recognize some stratigraphic distribution of the magnesium and calcium-rich rocks, but these have failed. On the contrary, it has been found that there are rapid sharp alternations of the two types in a way which strongly suggests that whatever dolomitization occurred must have taken place prior to emergence from the sea and probably contemporaneously with the formation of the deposit as has recently been described by Professor Branner as occurring on the coast of Brazil.

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*The distribution and structure of the Cockeysville marble as exposed in this synclinorium is discussed in detail in the succeeding paper by the author and his associate, Mr W. J. Miller.

No fossils have been found in the marbles, and as they are highly crystalline it is very doubtful if any will be found. The deposit, however, underlies the Wissahickon schist in exactly the same way as the Chester Valley marbles underlie the typical Wissahickon schists, which have been traced continuously into the Maryland areas.

WISSAHICKON FORMATION

The Wissahickon formation in Maryland occurs as a broad band wrapping about the older Baltimore gneiss and limestone areas and occupying practically all the territory between the Blue Ridge and the Coastal Plain deposits except those portions consisting of the sedimentary rocks already described, the overlapping Triassic sandstones of Carroll, Frederick, and Montgomery counties and the igneous rocks. This wide belt of rocks may be roughly divided into the Wissahickon schists and the Wissahickon phyllites with included limestone lenses. The line of separation between these two divisions is not marked stratigraphically by any pronounced change in lithologic character, and it is not entirely clear that the division is a stratigraphic one, although it seems probable that the phyllites in all instances are of as high or higher horizons than the more crystalline Wissahickon schists. It has been clearly shown by recent field work that the more crystalline Wissahickon schists pass by gradations into the less crystalline phyllites and sericite schists. The more crystalline aspects of the Wissahickon formation lie in the eastern part of the Maryland Piedmont, where they are in association with the older, more crystalline sedimentaries and the large masses of intruded gabbros, granites, and other igneous rocks.

The areal distribution of the Wissahickon formation may be discussed in four parts. The area of Wissahickon schists lying east of the broad phyllite band, which extends southward from the Susquehanna river to southeastern Carroll county, represents the area of highest crystallinity and closest similarity with the Wissahickon schists of the type locality near Philadelphia. The formation in this part of its development broadens from a narrow band at the Susquehanna river by increased folding about the anticlines of Baltimore gneiss and synclines of Cockeysville marble into a belt 10 to 15 miles broad as it crosses the Northern Central railroad. From this point it narrows somewhat to the southwestward, and the area is occupied in large part by the large mass of granite passing from Sykesville southwestward to Washington and extending thence many miles southward into Virginia.

North of the phyllite syncline occurs a corresponding mass of more crystalline Wissahickon schist. When, however, this is compared with the rocks on the southern limb of the synclinorium it is found that these rocks average slightly less crystalline and less metamorphosed than the corresponding rocks on the south. That they represent the same horizon seems to be well established by the areal distribution of the various masses, although it has been found impossible to carry the mapping of individual beds more than a few miles along the strike, and hence it has seemed inadvisable to attempt detailed cartographic representation. The Wissahickon schists on the west side of the syncline of phyllites passes southwesterly across the state, narrowing considerably in the southern portion of Carroll county and widening somewhat in passing southward to the Potomac river. The areal mapping of this region has been carried out in considerable detail by Mr Keith, of the United States Geological Survey, who has shown that the line of separation between the eastern and western portions of the Piedmont plateau, as laid down by Williams,* is in reality a sharply crenulate line, due to the folded structure of the area, which brings the contact between the phyllites and the more crystalline schists repeatedly to the surface.

The band of phyllite, forming a synclinal trough extending from the Susquehanna southward, enters the state from York county, Pennsylvania, continues as a belt, varying from 5 miles in thickness at the Susquehanna to about a mile at Whitehall, on the Northern Central railroad, whence it gradually widens southward to an average breadth of 3 miles in the southern part of Carroll county. The areal distribution indicates that we have a synclinal trough of considerable extent and well defined character, which is buckled at its center, and plunges northeastward and southwestward, reaching its maximum depth in the vicinity of Delta, Pennsylvania, where the Cardiff quartzite-conglomerate and Peachbottom slates are found folded within it. The southern termination of this phyllite belt has not been mapped in detail, and the limits here given are based on reconnaissance work on the part of Doctor Williams and the writer. Throughout its entire extent no limestone has been found up to the present time. It is, however, quite possible that small masses of this material have been overlooked, as the area traversed is a portion of the less dissected part of the Piedmont plateau, where the easy disintegration of the less resistant phyllites offers few exposures. The areal mapping, however, is easily carried on from a study of the fragments, which occur plentifully in the soil.

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* Bull. Geol. Soc. Am., vol. 2, 1892.

The rocks constituting the phyllite portion of the Wissahickon formation are essentially sericitic, chloritic, and occasionally talcose schists, which clearly show their sedimentary origin, and have been less metamorphosed than the Wissahickon schists already described. Two views are held regarding their relations to the contiguous formation. They may be regarded as an infolded younger series, as held by the late Professor Williams, or they may represent a less metamorphosed portion of the Wissahickon formation. It seems probable that there is truth in both views, and during recent years the impression has developed that they represent the upper portion of the Wissahickon formation, which has been less metamorphosed, but that they are not separated by any great interval from the more crystalline Wissahickon schists which border them on either side, and from which they cannot be separated by any sharp line. When crossing the boundary between the two formations one may recognize within comparatively short distances that a boundary has been passed, but up to the present no contacts between the two portions of the Wissahickon formation have been found. The interpretation of the phyllites here discussed does not necessarily or even probably apply to the more extensively developed phyllites lying a little farther west, though some of the latter may be the equivalent of the more eastern phyllite.

The western phyllitic rocks composing the area between Parrs ridge on the east and the sedimentaries lying at the base of Catoctin mountain occupy a broad belt which enters the state of Maryland from Pennsylvania and crossess the state into Virginia. Detailed work on this territory has not yet been completed, but the facts at hand would seem to indicate that they rest on the Shenandoah limestone of the Frederick valley, and are in turn overlain by the Triassic sandstones and shales. Passing westward from the more crystalline rocks east of Westminster, there appears to be a constantly decreasing amount of recrystallization and metamorphism until along their western margin they present characters similar to those of ordinary shales. Within this broad belt of phyllites occur numerous narrow valleys of limestone or crystalline marble and lenticular areas of chloritic and sericitic schists, which are manifestly the metamorphosed representatives of surface volcanoes. The western limits of the slightly altered phyllitic rocks and their relation to the sedimentary rocks of known age at the base of Catoctin mountain have thus been described by Professor Williams:*

> "If we follow the succession of strata eastward from Catoctin mountain, which bounds the Piedmont plateau on the west, we find above the hard Cambrian sandstone a little limestone, which, however, is immediately buried beneath the overlap of red sandstone. This blue limestone, whose fossils show it to be of lowest Silurian (Trenton) age, soon, however, emerges from beneath the overlying and unconformable Triassic (Newark) sandstones as a series of considerably folded beds, which are succeeded on the east and apparently overlain by carbonaceous and hardly altered shales. These are like those which occupy a similar position above the same limestone farther westward [Martinsburg shales]. Still beyond there follow with the earterly dip the thick beds of sandstone which compose Sugarloaf mountain. . . . The Sugarloaf sandstone passes on its eastern side upward by a gradual transition to shaly layers into sandy slates, and these again into the succession of sericite and chloritic schists, which compose the mass of the semi-crystalline area."

CARDIFF QUARTZITE

The quartzite and quartzose conglomerate which occur in the northeast part of Harford county form a narrow band apparently resting on the phyllite and underlying the Peachbottom slate, wrapping around the latter and extending beyond its southwestern limits to the valley of Broad creek. The formation is of small thickness and of slight extent.

PEACHBOTTOM SLATES

The Peachbottom slates extend as a narrow strip within the limits of the Cardiff quartzite and pass beyond it across the Susquehanna river into Lancaster county, Pennsylvania. The formation is composed entirely of characteristic blue-black slates, similar to the material put on the market, and the homogeneity of the formation is now so complete that it is impossible to perceive within it any succession of sedimentary beds. It is usually considered, however, that the central portion of the ridge differs somewhat from the sides, and that the formation represents the uppermost member in a tightly pinched syncline.

The age of these Peachbottom slates has been somewhat questionably determined on doubtful fossil evidence to belong to the Hudson River horizon of the Ordovician. If this correlation is correct, we have an upper limit fixed for the age of the deposits of the eastern Piedmont in Maryland, and an apparent confirmation of the position assumed that the Wissahickon is itself of Ordovician age, since there is no well defined and extensive line of separation between the Wissahickon and these locally developed slates.

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* Maryland, Its Resources, Industries, and Institutions. Baltimore, 1893, p. 66.

Age of the Formations

Within the Maryland Piedmont, so far as studied in detail, there are no means of locating accurately the position in the stratigraphic column of the four formations—Baltimore gneiss, Setters quartzite, Cockeysville marble, and Wissahickon schists and shales—but on either end of a continuous extension of these formations we have a sequence into sedimentary rocks of known horizon. On the east Doctor Bascom has shown that the Baltimore gneiss is pre-Cambrian, the quartzite Cambrian, the limestone Cambro-Ordovician, and the Wissahickon Ordovician. On the west the phyllites are apparently in the same relation to the known Cambrian and Cambro-Silurian deposits, although in this area the geological mapping has not been conducted in detail on account of the lack of satisfactory topographic maps. The conclusion from the facts at hand would therefore seem to warrant the correlation shown on page 340.

Opposed to this conclusion is the fact that directly on the strike of the Wissahickon schist are a series of more quartzose and more compact metamorphosed sediments, which have been regarded by Mr Keith, in his discussion of the geology of the Washington quadrangle, as Carolina gneiss, which, as defined by him, is pre-Cambrian. The grounds for the assigning of such an age to rocks of this region involve the areal work of Mr Keith in the region to the north and west of Washington, which has not yet been published on account of a lack of a proper topographic base.*

Structure and Structural Relations of the Piedmont Formations

For a proper understanding of the structural relations of the Piedmont deposits of Maryland it is necessary to recognize the character of the major structures along the eastern Atlantic coast from New Jersey southward and the position of the Maryland deposits with respect to these structures. The facts which are given below are familiar to students of American geology, but it seems desirable to restate them in relation to the Piedmont rocks under discussion.

Among the more striking features of the continental structure along

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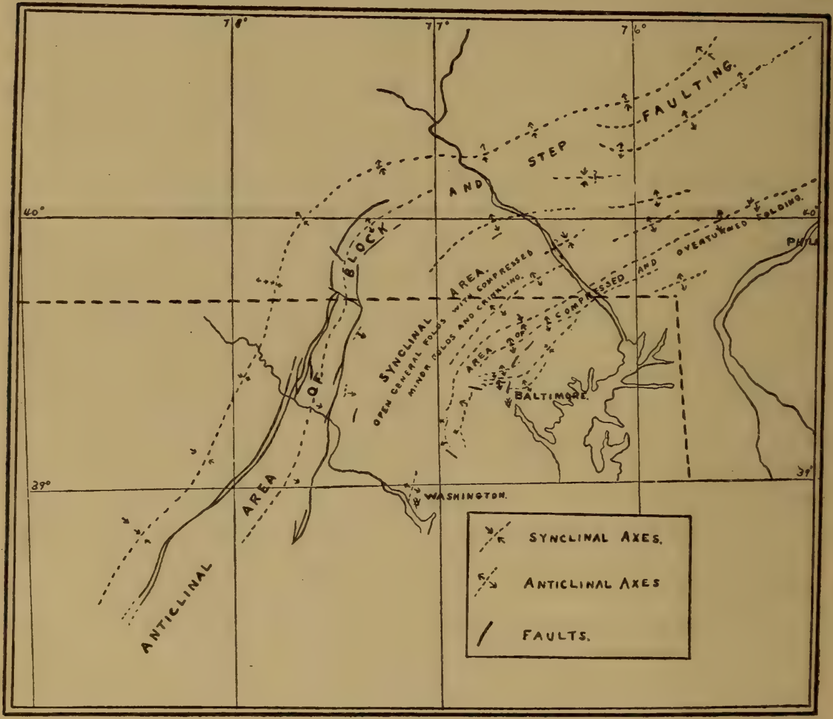
*A conference has been proposed for the workers in the Piedmont of Virginia, Maryland, Pennsylvania, and New Jersey, and an attempt will be made to reach a mutually satisfactory understanding as to the age correlations. Until this is done it is better to regard the age of the Maryland deposits as unsettled, with the evidence favoring the position taken in the preceding discussion.

	MARYLAND PIEDMONT.			PENNSYLVANIA PIEDMONT.	
	Western.	Central.	Eastern. Southern.	Eastern.	
Ordovician..........	Massanutten sandstone. Martinsburg shale.	Phyllite and Wissahickon schists.	Peachbottom slate. Cardiff quartzite. Wissahickon formation.	Wissahickon formation.	Hudson River.
Cambro-Ordovician..	Shenandoah limestone.	Cockeysville marble.	....	Chester Valley limestone.	Cambro-Silurian.
Cambrian...........	Antietam sandstone. Harpers shale. Weverton sandstone. Loudoun formation.	Setters quartzite with argillaceous upper member.	....	Chickies quartzite.	Cambrian.
Pre-Cambrian.......	Granites, schists, etc...	Baltimore gneiss....	Baltimore gneiss....	Baltimore gneiss..	Pre-Cambrian.

the eastern coast of the continent is the generally northeasterly trend of the folds constituting the Appalachian system. This structure holds for most of the territory from Alabama to Maryland and from the Canadian boundary to New York city. In the region of Pennsylvania, however, there is a marked deflection of these parallel folds, on account of which they are found to strike almost due east and west across the state from the Potomac to the Delaware. Beyond the Delaware the formations gradually resume their northerly trend. The change in direction of the folds of the Appalachians is readily seen in the geological map issued by the state of Pennsylvania and in smaller geological maps of the United States issued in the standard text-books. For the present purpose the structure is clearly brought out by a consideration of the areal distribution of the limestone of Ordovician age, which are known by various names—Shenandoah, Lancaster, Chester Valley, Trenton, etcetera—throughout the long course of its development. A study of a map (figure 1) showing the geology of the Virginias, Maryland, and Pennsylvania permits one to trace the extent of this formation from its northeast course along the Shenandoah valley on the west side of the Blue Ridge to the north end of South mountain in the region between Chambersburg and Carlisle, Pennsylvania, where the trend changes from northeast to east. This easterly trend is pursued to Harrisburg and the vicinity of Reading, when a series of folds causes the areal distribution to extend somewhat farther north, although the structure lines still remain approximately east and west. If one disregards the overlaps of Triassic in this portion of Pennsylvania, it may be seen that the Cambro-Ordovician limestone widens by a series of folds along the Susquehanna and Schuylkill rivers and extends back southward along the eastern flank of the South mountain anticline as far as the Potomac river. Within this broad region of limestone may be noticed several anticlines of gneiss bordered by Cambrian quartzite and surrounded by the Cambro-Ordovician limestone, which in few instances appears overlain by shales and schists of Ordovician (Hudson River) age. The southernmost portion of the Cambro-Ordovician limestone appears in many cases, as at Frederick, near Strassburg, at Downingtown, and on the Schuylkill, to be on the south side of anticlines, and thereby representing the northern limb of synclinoria, which possess the general axial features noticed in the Ordovician limestone. Overlying the limestone along its southern and eastern borders are the phyllites and less crystalline representatives of the supposed very ancient members of the Piedmont plateau. Disregarding the possibility of extensive thrust faults, for which the facts in the area rarely indicate any probability, the most natural inference would be that these shaly phyllites are Ordovician deposits lying in an eastern geo-syncline whose axis conforms to the general character of the continental structure. Such a geo-syncline would be between the Blue Ridge and Great valley on the north and west and the accumulation of metamorphosed sediments and igneous rocks on the east. This inference is, moreover, corroborated by the character of the folding where it has been deciphered in eastern and central Maryland.

The map still further shows that, while the forces at work to produce the Appalachian structure along the Atlantic coast were exerted northwest and southeast, the distribution of force in the Maryland Piedmont was very much more complex, since the center of the major curve of the continental structure lies approximately coincident with the city of Baltimore. This fact would seem to indicate that whatever forces were at work in the Maryland Piedmont during the formation of Appalachian structures must have worked on lines radiating from a central point, and that if any difference of force along these lines occurred there must have been developed more or less torsional stress, and that such torsional


78°
77°
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STEP
AND
BLOCK
FAULTING.
AREA OF COMPRESSED AND OVERTURNED FOLDING.
SYNCLINAL AREA.
OPEN GENERAL FOLDS WITH COMPRESSED MINOR FOLDS AND CRINKLING.
ANTICLINAL
AREA
OF
BALTIMORE.
WASHINGTON.
PHILA
SYNCLINAL AXES.
ANTICLINAL AXES
FAULTS.

Figure 2.—*Sketch of axial Lines for major Structures of the Piedmont.*

action would be likely to produce folds of shorter major and greater minor axes than are the rule in the long-drawn-out ellipsoids of Appalachian folding. The effect of these forces must thus have a direct expression in the areal distribution of the various deposits found in the Piedmont of Maryland, and, conversely, if such results are found there is developed a reasonable probability that the present major structures of the Maryland Piedmont were produced by the same forces and at the same time as the Appalachian folds.

Starting on the west with the faulted and sharply folded anticlines of the Blue Ridge bordered on either side by Cambrian rocks and associated igneous masses (compare figures 1 and 2), one may pass successively eastward through Maryland across the gently eastward sloping limestones of the Frederick valley, which in turn, as above described, appear to dip under the so-called semi-crystallines or phyllites of the Piedmont. While the detailed structure is not fully known, it seems probable that there exists in this part of the state a very open general structure by which the beds lie almost horizontal in their major folds, with a much compressed subordinate structure, which, because of the numerous minor folds, give to the rocks an appearance of highly inclined and complicated folding. East of Parrs ridge the rocks are more crystalline and the folding a little more pronounced in its general features, with a change in strike of the axes of the major folds in conformity with the change of direction in the continental folding previously described. Between the area of open folding just described on the northwest and the cover of Coastal Plain deposits on the southeast one may readily recognize in the Maryland area the broad synclinal trough of the eastern phyllite belt and that of the Cockeysville marble, separated by the dome-like anticline of the Baltimore gneiss already described. Still farther east, separated from the Cockeysville synclinorium in part by a southern anticlinal border of Baltimore gneiss, is a broad zone of igneous rocks composed of gabbros, granites, and other plutonic types which occupy most of the eastern border of the Piedmont between Wilmington, Delaware, and Laurel, Maryland.

Minor igneous masses are found with the same general trend, and these are seen to be rather closely associated with the structure lines of the region, occupying as they generally do anticlinal axes. This relation to the structure lines is particularly shown in case of the long belt of serpentines extending from Lancaster county, Pennsylvania, across the Susquehanna river almost to the nose of the northern anticline of the Baltimore gneiss. Farther to the southwest, almost on the strike of this anticlinal axis, begins a long and somewhat narrow body of granite extending from Sykesville, on the Baltimore and Ohio railroad, southward across the Washington quadrangle and thence continuing probably as far as the Fredericksburg region.

EASTERN PIEDMONT OF VIRGINIA

Our knowledge of the Piedmont formations in Virginia is by no means equal to that of Pennsylvania and Maryland, since little or no work has been done in the area between the Blue Ridge on the west and the Coastal Plain deposits on the east since the days of the Rogers. There have appeared, however, occasional local descriptions of limited areas, and these the present writer has attempted to correlate with the facts given in the early reports of the Virginia survey, and these correlations have in a measure been checked by personal reconnaissance as far south as the James river. It should not be thought, however, that the following statements are regarded as any more than a working hypothesis, which may aid in the ultimate interpretation of the Virginia Piedmont.

A study of the Piedmont geology of Virginia from the literature impresses the student at once with several generalizations, the strongest of which is that in all of the previous work little or no attempt has been made by the different students to recognize and map the different formations within the limits of the Piedmont east of the mountains. A second impression from the descriptions published is that formations similar to those recognized in Maryland extend across the state of Virginia with a trend similar to that of the Blue Ridge and the Shenandoah valley farther west, with the exception, however, that the limestones and marbles are apparently absent in any extensive development comparable to the areas of Cockeysville marble in the Maryland region. On the other hand, the little lenses of marble which have been recognized and but little studied in the western part of the Maryland Piedmont may be traced, where the older rocks are not obscured by the Triassic sandstones, all along the western side of the Virginia Piedmont from the Rapidan to the Staunton river and probably to the North Carolina line.

Again, it may be noticed that the igneous rocks occupy similar positions in Virginia to those in Maryland, with the exception that they are relatively less abundant, and, so far as the facts at hand indicate, are usually granite and not gabbro, although the writer has found hornblende schist in the valley of the James which probably represents metamorphosed gabbros, and the lithologic descriptions suggest that gabbroic rocks, more or less metamorphosed, may be found in several parts of the state. The principal masses of granite so far recognized are (1) the southward continuation of the granite of the Catoctin belt recognized by Keith,* which evidently extends southward into Albemarle county; (2) the southward continuation of the Sykesville-Washington granite area, which apparently is more or less continuously developed from Washington to Fredericksburg, and possibly includes the granitic masses at Columbia, on the James river, which is approximately on the strike, according to the general trend of the formations; (3) the granitic mass in the area about Richmond, which conforms in position to the more easterly granite of the Maryland area.

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* Fourteenth Ann. Rept. U. S. Geol. Survey, pp. 285–395.

When an attempt is made to decipher from the remarks and lithologic descriptions a general clue regarding the structure of the Virginia Piedmont one may be led to the following suggestions: On the west is a well defined anticline of the Blue Ridge with Cambrian and Ordovician rocks on the west and the rocks of the Piedmont on the east. Throughout most of the distance from the Potomac to the James the analogues of the Blue Ridge and Catoctin mountains of Maryland may be traced as companion topographic features. It is, however, to be noted that in passing southward these parallel ridges become separated and the easternmost less prominent and broken up, suggesting the southward dying out of the eastern part of the double-topped anticline exhibited in the Maryland area. With the Blue Ridge on the west and a southward continuation of Catoctin mountain, represented by Bull Run, Southwest, Carters, Green, and Finley mountains, on the east are associated amygdaloidal chloritic rocks representing surface flows, which have been termed by Mr Keith "Catoctin schist" and occasional meta-rhyolites. East of the more mountainous part of the Piedmont little is known of the structure in the northern part of Virginia south of the Washington sheet, but it seems reasonably probable that we have here a broad synclinal area comparable to that of the western Piedmont in Maryland. The rocks are in large degree similar and the areal distribution and position of the region with respect to the Maryland territory support this assumption.

South of the James river, if one may judge at all from the meager descriptions published, including the sections of the Virginia survey, there are a series of more sharply compressed folds, which bring to the surface more crystalline gneisses comparable in character to the Baltimore gneisses of Maryland. Associated with these are less crystalline schists similar to the Wissahickon formation of Pennsylvania and Maryland, but differing apparently by a somewhat less pronounced degree of metamorphism. It is in this area that Darton * found fossils indicating the Paleozoic age of these deposits. Southward from Amelia court-house is the suggestion of a large synclinorium plunging to the southward along a line from Amelia, Virginia, to Warrington, North Carolina, which would

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* Amer. Jour. Sci., 3d ser., vol. xliv, 1892, pp. 50-52.

explain the relative broadening of the Piedmont along the Virginia-Carolina boundary, where the structures of the west are trending southwestward and those on the east in a more southerly direction.

CONCLUSIONS

The preceding survey of the present state of knowledge regarding the formations and structure of the Piedmont in Maryland would seem to warrant the following conclusions:

(1) The four formations recognized by Doctor Bascom in the Philadelphia area may be traced across the state of Maryland, and they probably constitute the bulk of the rocks forming the Piedmont of Virginia, which have heretofore been mapped as a unit.

(2) The structural character of the Piedmont from Trenton southward to southern Virginia is similar throughout to the Appalachian structure of the less metamorphosed Paleozoics to the westward—that is, one may recognize within the Piedmont a series of long and narrow folds and arches trending parallel to the trend of the Appalachians. An exception to this general rule is noticeable in the central Maryland area, which lies toward the center of a local curve in the Appalachian structure, where the structural forms are more nearly circular than is the general rule in the Appalachians.

(3) The age of the different formations in the Piedmont is still unsettled, with the weight of opinion so far presented in favor of an early Paleozoic age for the formations immediately overlying the Baltimore gneiss.

(4) The conclusions reached, so far as they relate to Maryland, are based on a detailed mapping or intimate knowledge of practically all of the Piedmont, but those of Virginia must be regarded as merely suggestive and warranting credence only in so far as the principles of interpretation established by detailed work for part of the province permit of application to contiguous areas.

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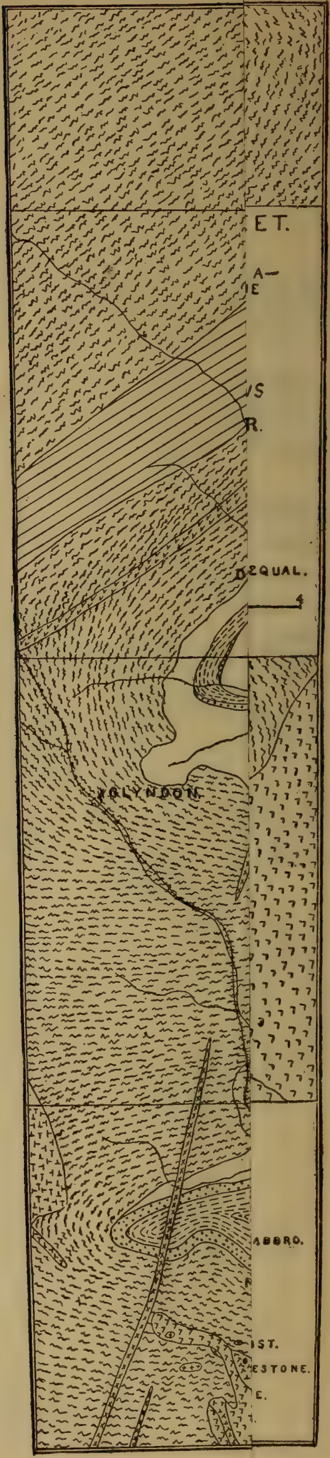
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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 16, PP. 347-366, PL. 65 MAY 31, 1905

COCKEYSVILLE MARBLE

BY EDWARD B. MATHEWS AND W. J. MILLER

(Read before the Society December 30, 1904)

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INTRODUCTION

In earlier papers* the senior author has presented an interpretation of the structure of the Piedmont region as exhibited in Maryland, and

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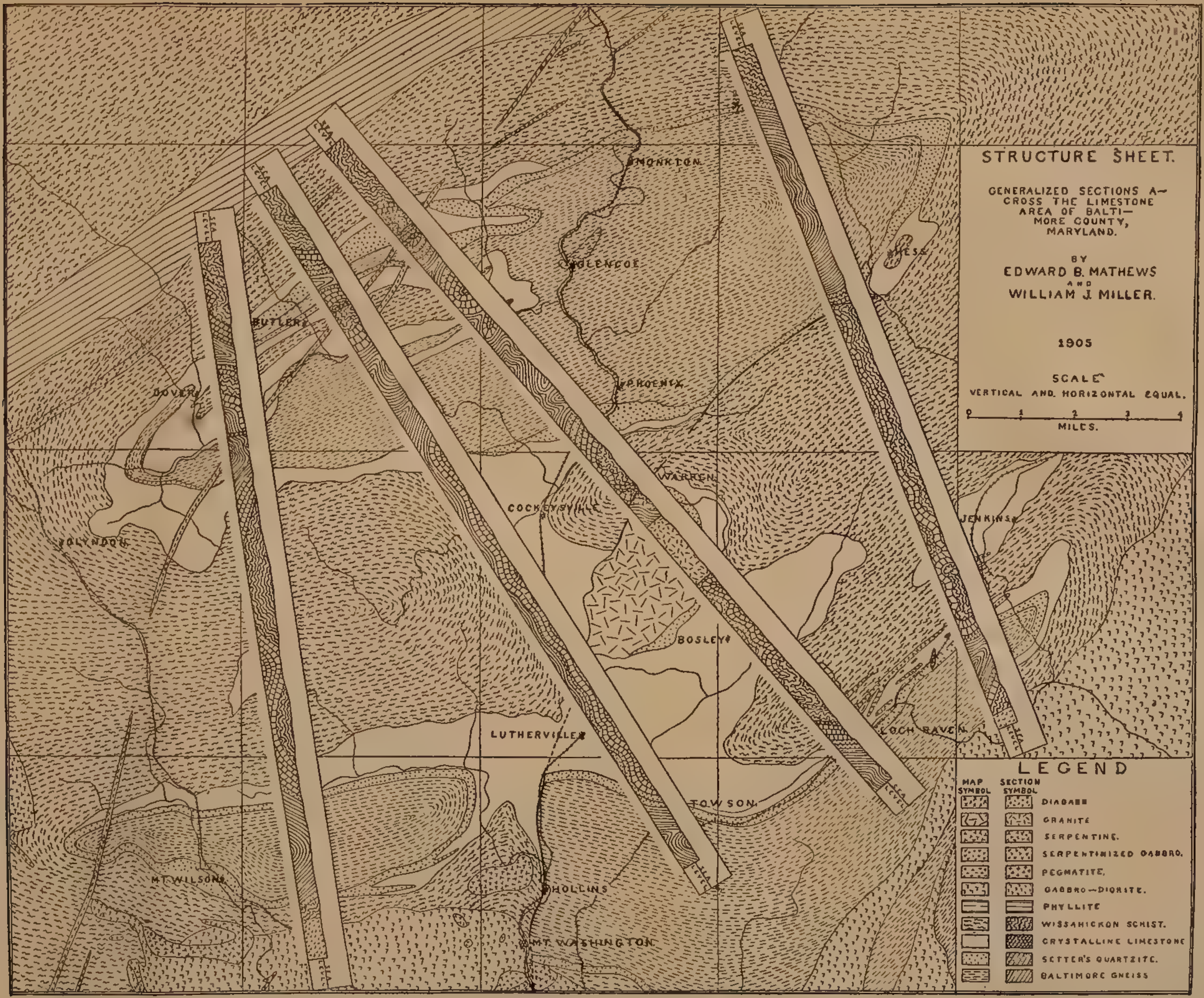
* Amer. Jour. Sci., 4th ser., vol. xvii, pp. 141-159, 1904; see also paper in this volume, pp. 329-346.


STRUCTURE SHEET.
GENERALIZED SECTIONS ACROSS THE LIMESTONE AREA OF BALTIMORE COUNTY, MARYLAND.
BY
EDWARD B. MATHEWS
AND
WILLIAM J. MILLER.
1905
SCALE
VERTICAL AND HORIZONTAL EQUAL.
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MONKTON
GLENCOE
BUTLERS
DOVER
PHOENIX
WARREN
COCKEYSVILLE
GLYNDON
JENKINS
BOSLEY
LOCH RAVEN
LUTHERVILLE
TOWSON
MT. WILSON
HOLLINS
MT. WASHINGTON
LEGEND
MAP SYMBOL
SECTION SYMBOL
DIABASE
GRANITE
SERPENTINE
SERPENTINIZED GABBRO
PEGMATITE
GABBRO-DIORITE
PHYLLITE
WISSAHICKON SCHIST
CRYSTALLINE LIMESTONE
SETTER'S QUARTZITE
BALTIMORE GNEISS

GENERALIZED SECTIONS ACROSS LIMESTONE AREA OF BALTIMORE COUNTY, MARYLAND

suggested that it is possible to recognize in the highly crystalline and much metamorphosed rocks of the area lines of bedding which indicate that the crystalline rocks of the Piedmont possess a general structure comparable to that of the Appalachians lying to the westward. In the present paper it is proposed to give a somewhat more detailed discussion of a local area, the special problem of the junior author, in which the type of folding is well exhibited and more easily seen because of the sharp differences, lithological and topographical, between the limestone or marble and the adjacent rocks.

The area under discussion occupies a tract of approximately 300 square miles, represented on the southern portions of the Belair, Parkton, and Westminster sheets and the northern part of the Gunpowder, Baltimore, and Ellicott sheets of the United States Geological Survey, or, in other words, between 76 degrees 25 minutes and 76 degrees 50 minutes west longitude and 39 degrees 20 minutes and 39 degrees 40 minutes north latitude. The Northern Central railroad from Baltimore to Harrisburg passes directly across the region, while the Western Maryland from Baltimore to Hanover skirts its western limits.

Rocks of the Region

LIST OF THE FORMATIONS

Within the limits of the region under discussion are exposed the rocks of the four formations, namely, (1) Baltimore gneiss,* (2) Setters † quartzite, (3) Cockeysville † marble, (4) Wissahickon * mica-schist, mica-gneiss, and phyllite, described by the senior author in the discussions already referred to. The lithological characters of these different formations vary somewhat from place to place, but as exposed in the vicinity of the Cockeysville marble may be described as follows :

BALTIMORE GNEISS

This is a highly crystalline gneiss, composed of quartz, feldspar, and mica, or hornblende, with accessory minerals so distributed as to produce a well marked gray banded gneiss, the individual bands of which vary from a fraction of an inch upward. The average thickness, however, is quite small. Some of these beds are highly quartzose, resembling a micaceous quartzite or less frequently a vitreous quartzite; others are rich in biotite or hornblende, producing dark to black rocks indistinguishable in a hand specimen from the mica and hornblende schists and gneisses derived from igneous rocks by metamorphism. Through these banded gneisses are intruded pegmatite and aplitic dikes more or less parallel to the regular banding of the gneiss. Many of the broader bands composed usually of hornblende-schists are probably of igneous origin, as has recently been shown for similar rocks in New York by Professor Julien. The banding of these gneisses has generally been regarded as secondary, but the fact that the strike and dip of the bands coincide with the strike and dip of the sedimentary rocks around the nose of folds and on either flank makes it seem probable that they are very often, if not always, indicative of original variations in sedimentation.

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*Accepted by the Committee on Geologic Names of the U. S. Geological Survey.

†Old terms used provisionally until an agreement on names is reached.

SETTERS QUARTZITE

This formation as developed in its type locality, Setters ridge, in the southwest corner of the area under discussion, is a fine grained, somewhat saccharoidal, thin-bedded quartzite of white, cream, or light-brown color. The beds are usually separated by thin films of sericite in tiny glistening flakes. On the surface of these mica-covered planes frequently occur black tourmaline crystals, which, as first shown by Williams, give evidence of movement along these planes. In other portions of the area, especially in the vicinity of Butler and along the Gunpowder river west of Glencoe and east of Phœnix, the rock becomes more vitreous and less clearly bedded. This is especially true in the cutting of the Gunpowder just below Warren, where the quartzite is exposed in a double-topped anticline of moderate size.

Resting on top of the more homogeneous and quartzose members occasionally occur quartzite bands interbedded with micaceous layers, which in the hand specimen appear to be garnet schists, practically indistinguishable from the Wissahickon schist, which occurs higher in the column. At times the quartzitic layers become insignificant and the whole mass looks like a Wissahickon schist. There are, however, minor features which can not be put into words, but which may be recognized during the progress of continuous mapping, which render the aspect of the exposure and the character of the rock valuable as aids in mapping. It was at first thought that this portion of the quartzite formation was in reality a faulted-in representative of the Wissahickon, but detailed mapping of critical areas, where the formations possess more marked minor folding, show that a fault can not explain the development of this local member of the quartzite formation.

The Setters quartzite is generally found dipping at a steep angle, and because of its resistance to weathering agencies it is often a topographic feature which aids in determining its limits.

COCKEYSVILLE MARBLE

The carbonate rocks, which because of their more extensive exploitation and peculiarities in weathering have been of especial service in deciphering the structure of the Maryland area, consist of calcitic and dolomitic varieties. The main mass of the rock is magnesian and would be classed as a crystalline dolomite. This is not a mapable unit as opposed to the marbles, which are of pure calcium carbonate, and the investigations of the junior author, so far as they have progressed, do not warrant any statement indicating a stratigraphic difference in position between the lime and magnesian rich rocks. The intimacy of association may be judged from the following detailed section made by the junior author:

Section showing alternations of calcitic and dolomitic marble

	Feet	Inches
Medium grained, calcitic	5	
Rather coarse grained, clear, white, calcitic	1	2
Coarse grained, bluish, pyrite, calcitic	..	4.5
Very fine grained, friable, dolomitic	..	1.5
Very pure, coarse grained, calcitic	..	6
Fine grained, gray, micaceous, dolomitic	..	10
Fine grained, grayish brown, impure, calcitic	..	4
Fine grained, pure, dolomitic	..	6
Medium grained, blue, calcitic	1	8
Medium to coarse grained, white, calcitic	..	10
Fine grained, pure, dolomitic	..	7
Medium grained, blue, calcitic	1	5
Fine grained, white, dolomitic	..	5
Medium to coarse grained, brown, calcitic	1	
Medium grained, impure, bluish, calcitic	1	6
Fine grained, micaceous, gray, dolomitic	2	
Medium grained, pale blue, impure, calcitic	1	8
Coarse grained, white, calcitic	2	
Fine grained, brown, dolomitic	1	5
Medium to coarse grained, calcitic	1	11
Very coarse grained, white, calcitic	..	9
Fine grained, brown, dolomitic	..	2.5
Medium grained, blue brown, calcitic	4	6
Fine grained, micaceous, white, dolomitic	..	2
Coarse grained, pure, calcitic	..	5
Fine grained, micaceous, dolomitic	..	2
Coarse grained, white, calcitic	..	4
Fine grained, micaceous, dolomitic	..	1
Coarse grained, pure, white, calcitic	1	
Fine grained, pure, dolomitic	1	2
Fine grained, micaceous, dolomitic	6	
Fine grained, brown, dolomitic	..	7
Coarse grained, pure, friable, calcitic	2	
Fine grained, brown, dolomitic	1	
Coarse grained, pure, calcitic	..	1.5
Fine grained, brown, micaceous, dolomitic	..	3

	Feet	Inches
Coarse grained, pure, calcitic	..	10
Fine grained, micaceous, dolomitic	2	
Faulted, beds disturbed, calcite veins	10	
Fine grained, dolomitic beds	12	
Medium grained, light blue, calcitic	4	
Total	73	

The different layers within the formation vary widely in coarseness of grain from the fine, almost statuary, marble obtained at the Beaver Dam quarries at Cockeysville to the coarse so-called alum stone, in which the invividual grains may reach a diameter of one-half, three-fourths, or even 1¾ inches, as is found in many parts of the region. So far as any generalizations can be drawn regarding the variations of texture, it appears that the dolomitic or magnesian-rich varieties are finer grained and more compact as compared with the purer lime carbonate rocks, which are generally coarsely crystalline. Another feature of these rocks is the presence of impurities along fairly well defined lines which have for the most part been recrystallized into magnesium silicates. These lines of impurity may separate the different lime-rich beds from those rich in magnesium, or, what is more commonly the case, dolomitic layers from each other. It seems to be rather generally the rule that the impurities are more intimately associated with the layers rich in magnesium than with those rich in lime, but frequent exceptions may be found to this statement. Among the most common accessory minerals found in this formation are phlogopite, biotite, muscovite, and iron pyrites; tremolite, quartz, and occasional tourmaline are, however, more frequently found within the limits of individual beds.

The general rule employed in field work, based upon innumerable acid tests, has been that the coarser grained beds are calcitic and the fine grained beds are dolomitic; each type is white, cream, brown, or somewhat dirty in color.

WISSAHICKON SCHIST

This formation consists of a series of highly micaceous, very schistose, and often crinkled aggregates of quartz, more or less chloritized biotite and garnet, with accessory orthoclase, cyanite, staurolite, etcetera. With the increase of feldspar the rock passes into a gneiss. This, however, is less distinctly banded than the gneisses of the Baltimore formation. The individual beds in this type are only indistinctly marked, and their separation from the well-defined lines of foliation is often attended with considerable difficulty. The dip of the foliation varies somewhat, but is usually about 45 degrees, while the effective dip of the individual beds, which themselves are highly crinkled, may vary from 0 to 90 degrees, representing in their general structure open folding, but in their intimate structure the folds are frequently much compressed and often overturned and slightly faulted.

IGNEOUS ROCKS

Through these several sedimentary formations have been intruded igneous rocks ranging in composition from granites to peridotites. The main development of the igneous rocks, however, lies outside of the field selected, only the extreme members being represented, in the granite between Warren and Cockeysville and in the serpentinized peridotite of the Bare hills. These igneous rocks were intruded either during the folding of the rocks or subsequently.

There are also several lines of diabase boulders representing dikes which have been correlated with the great Triassic intrusions farther north.

Areal Distribution of the Rocks

IN GENERAL

The rocks of the region, as shown by the accompanying sketch map (figure 1), may be roughly grouped into three broad belts extending parallel to the strike of the formations from northeast to southwest. On the south are two anticlinal areas of the Baltimore gneiss, separated from each other along the strike by a fault and sharp folding, while on the north is an oval anticlinal area of Baltimore gneiss about 15 miles in length and 5 miles in breadth in its widest point. Between these two areas in a broad synclinal trough occur in regular succession the Setters quartzite, Cockeysville marble, and Wissahickon schist, the latter occupying the larger portions of the area and connecting on the north, east, and west with the larger body of Wissahickon, which extends diagonally across Maryland from the southwestward continuation of the type Wissahickon of Pennsylvania to the Potomac river on the west.

DISTRIBUTION OF BALTIMORE GNEISS

Southern area.—The southern development of the Baltimore gneiss on the south side of the Greenspring and Mine Branch valleys falls into two distinct areas, separated by the limestone and Wissahickon valley of lake Roland and possibly by a fault. On the west is a lenticular anticlinal mass entirely surrounded by the Setters Ridge quartzite, wherein the bands of Baltimore gness stand at a high angle, ranging from 40 to 75 degrees at the center, and strike parallel to the major axis of the ellipse except near the ends, where their strike follows the general contour of the areal distribution, and the dip lessens to between 10 and 30 degrees. The exposures within this area, which rises to the level of the Piedmont plateau, are not good, and it is not possible to make a detailed correlation of any of the beds found within it. The facts observed, however, clearly indicate that we have here, as is so often the case, an anticlinal zone which plunges downward at either end. The best exposures of the formation are those along the northern part of Park Heights avenue between Eccleston and the road from Pikesville to Rockland, which is known locally as the "Old court road."

The eastern half of the Baltimore gneisses on the southern borders of the area extends from the north and south fault along the Northern Central railroad between Hollins and Sherwood eastward to Towson, and thence across the Gunpowder river to the vicinity of Glenarm, where it terminates in a steep, tightly pinched anticline. On the south the limits of the Baltimore gneiss have not been entirely worked out, but the detailed mapping of the late Professor Williams would indicate that it is bordered by the quartzite which extends from the Northern Central railroad near Mount Washington to lake Montebello, within the northeastern limits of the city of Baltimore, where the crystalline rocks are covered by the later unconsolidated deposits of the Coastal plain. On the east this formation is bordered at first by the quartzite and limestone, but these successively pinch out within a mile or two of the eastern nose of the anticline, and do not appear along the deeply cut trench of the Big Gunpowder river. It is probable that the southern limit is a a strike fault or the contact with the large gabbro mass which extends in a northeasterly direction across Maryland from the eastern limits of Baltimore city to the Susquehanna river near Darlington. Throughout this region of Baltimore gneiss the exposures are poor, due to the high state of cultivation of the land, its plateau-like character, and the presence of numerous well kept country estates. There are, however, numerous exposures along the Gunpowder and in some of the other streams, but the gneisses at this point are intricately penetrated by numerous granitic and grabbroic intrusions.

Northern area.—The northern area of Baltimore gneiss is broadly an ellipsoidal mass, representing a large anticlinal dome, which, like the smaller one of the south, plunges at either end. This plunging of the anticline to the westward brings the overlying formation down to the surface of the country, and thereby causes the surface exposure of the Baltimore gneiss to narrow rapidly to the westward of the Northern Central railroad. The marked differences in character between the quartzites, limestones, and Wissahickon schists allow the working out of the structure in greater detail than is possible in the eastern half of this anticlinal dome; but the observations within the Baltimore gneiss in the eastern half of the lenticular area, to the eastward of Monkton and Phœnix, are entirely in accord with those of the western portion, and indicate that the gneisses occur in numerous tightly pinched folds, possessing a common strike parallel to the major axis of the dome and steep dips, some of the time to the north and some of the time to the south. On the whole, the northerly dips predominate, indicating that the anticline is somewhat overturned to the south.

Numerous exposures of the gneiss are found along the Big and Little Gunpowder rivers and their tributaries, but they are few and unsatisfactory, except for areal mapping, in the plateau portions of the region which is a prosperous farming community under a good state of cultivation. The exposures encountered show that the Baltimore gneiss is penetrated in the northern area by igneous intrusions, now much metamorphosed, of granitic and gabbroic materials. The former are altered to granite-gneisses and the latter to hornblende-schists.

DISTRIBUTION OF SETTERS QUARTZITE

General characteristics of the exposures.—This quartzite formation, with its local variations toward a garnet-schist, occurs on the borders of the Baltimore gneiss area, usually as long, narrow ridges, rising steeply from the level of the limestone valleys to the surface of the plateau or upland, and usually may be found outcropping where the streams have cut across the strike. Its exposures are highly characteristic, though generally poor, on account of the small rhomboidal form of the fragments into which it breaks when fine bedded and somewhat micaceous. When highly quartzose and more compact it is likely to be confused with the Baltimore gneiss, and when very micaceous and carrying garnets it is likely to be confused with the Wissahickon schists which overlie the limestones.

Southern area.—The ocurrence of the quartzite about the Baltimore gneiss dome in the southwestern part of the area may be traced almost continuously, by means of fragments, around the entire zone, and exposures in which it is possible to obtain the dip and strike of the beds may be found frequently. In this area, the typical area for this formation, the rock is characteristically thin-bedded, the beds being separated by films of sericitic mica. Along the northern border of the anticline from Rockland to Red Run the rock dips uniformly northward underneath the marble at an inclination of about 70 degrees. On the south the dips are less uniform, being sometimes to the north, but generally to the south, indicating a minor folding in the beds and some overturning, as is brought out more clearly by the small stringers of marble found infolded with them. On the end of the anticline to the west the beds change rapidly in strike from east-northeast to northeast, through north and northwest to west-northwest. On the eastern end the strikes of the beds change similarly from east-northeast to northwest, through north to north 45 degrees east, the dips in all cases being away from the underlying Baltimore gneiss and beneath the overlying marble or Wissahickon schists, as the case may be.

The eastern exposures of quartzite forming the ridge on the south side of the limestone valley extending from Sherwood to Glenarm are less satisfactory than those just described, but wherever observed indicate a northern dip of somewhat less inclination until near the eastern end of the anticlinal fold, where the beds rise steeply on the north with a northerly dip of 75 degrees and an easterly dip on the south of about 40 degrees. The anticlinal character of the structure at this point is usually well brought out for Piedmont conditions by the formation of a triangular hill of quartzite produced by the nose of the fold, which is cut through by Long Green creek about a mile from its apex. The strikes of the quartzite may be traced at this point along the top of the ridge, where they show progressive changes in position through all azimuths from north 45 degrees east, through west and north, to north 30 degrees east, and even reach north 60 degrees west near the crossing of the Harford turnpike. The character of the quartzite in this part of the fold is not that typical of Setters ridge, but shows the development of more mica with accessory garnets and occasional cyanite.

Throughout this entire southern region the quartzite shows the average thickness of about 500 feet.

Northern area.—The areal distribution of the quartzite about the northern dome of Baltimore gneiss is much less constant than is the case about the southern areas, and there are many evidences of a marked erosional conformity and a few strike faults in this part of the region. The occurrence of the quartzite may be traced almost continuously from a few miles west of the Northern Central railroad near Cockeysville along the southern side of the road to the northeastern nose of the fold on the road between Taylor and Jarrettsville, where a well defined V-shaped hill is formed by the upturned beds of the quartzite, and thence westerly on the northern side of the dome. The quartzite is not distinguished in the cut of the Northern Central railroad north of Monkton, but the typical tourmaline-bearing mica-schist is found outcropping on the hills across the river, and thence may be traced along the westerly side of the dome in several bands to the southwestern nose of the anticline, where it may be found in a few poorly developed exposures. The exposures along the northern boundary east of the Northern Central railroad are very poor, and the presence of the quartzite is only actually established at a few points, owing to the cover of soil and the close similarity of the Baltimore gneiss at this point. It is quite possible that the quartzite is cut out locally, as it can not be recognized in the well exposed cuts along the railroads just north of Monkton. If this is so, the lack of quartzite only occurs for a short distance along the strike, as it is exposed in the road from Monkton to Hereford, just west of the Gunpowder river, and from this point may be traced without interruption through Pine Hill to the sharply folded region between there and Glyndon.

Along the southwestern limits of the Baltimore gneiss the quartzite is seldom found between it and the overlying marble, and wherever so found it is usually very thin and poorly developed. It has been noted along the northern edge of the Worthington valley near Councilmans run and a little farther north above Slades run, but is apparently lacking along the contact between the limestone and the Baltimore gneiss as exposed along Western run. Such a rapid thinning of the quartzite from a thousand feet or more in the ridges between Butler and Stringtown to zero in Western run, a distance of less than 2 miles across the strike of the folds, is quite unusual, but no facts were found indicating a fault, and many observations point to a rapid thinning, due apparently to an erosional unconformity.

The unusual and rather peculiar development of garnet-schists and garnet-mica-schists interbedded with the quartzite and apparently constituting an upper member of that formation is best exhibited in this northern region, especially between Pine hill and a point 1 mile northwest of Butler, in the Stringtown valley. The quartzitic layers at this point are not well developed, and the outcrops along the sides of the hill strongly suggest the Wissahickon schist. The true position of this bed is, however, shown by the folding of the quartzite-garnet rock and limestone northwest of Belfast along Buffalo creek, where the areal distribution and structural observations seem to exclude the possibility of a fault and demand the interpolation of an upper member in the quartzite formation. This same conclusion is the most satisfactory deduction from the observations made in the quartzite formation along the gorge of the Gunpowder between Warren and Royston branch, where the garnetiferous rock interbedded with quartzitic layers is found resting on more quartzose beds, and beneath the marble the whole conforming with the structural relations shown by numerous exposures of marble in the valley of Royston branch. The detailed character of the structure at this latter point will be more fully discussed in a later portion of the paper.

DISTRIBUTION OF COCKEYSVILLE MARBLE

Areas in general.—The Cockeysville marble lies in a synclinal trough between the southern and northern Baltimore gneiss areas and in the synclinal folds on the northwest side of the northern anticline and outcrops frequently within the limits thus outlined wherever the formation is not covered by the Wissahickon schist. The occurrence of the carbonate rocks at the surface is always marked topographically by the occurrence of limestone valleys, most prominent among which are the Greenspring and Mine Bank valleys, lying to the north of the southern Baltimore gneiss, between it and the overlying Wissahickon. Between these two valleys and the corresponding valleys farther north the Wissahickon gneiss has been removed, giving a very low divide in the drainage system underlain by crystalline limestones extending from Lutherville to Cockeysville. This, together with the narrow portion of the Worthington valley and that of Green run, which border on the southern flank of the northern anticline, represent crudely a recumbent letter H. The limestone also extends northeastward from Lutherville, forming the Dulany valley, which in turn has a small offshoot of the limestone (the complementary flank of a small anticline) which runs up the valley of the Gunpowder to the mouth of Royston branch, where the limestone leaves the Gunpowder valley and occurs in a gentle anticline in the valley of the smaller stream.

From the western end of the Worthington valley the limestone wraps around the narrow nose of the northern anticline and outcrops in a series of narrow parallel valleys, separated by anticlinal ridges of quartzite and gneiss or synclinal areas of Wissahickon schist.

Beside these larger areas, which may be traced as one continuous mass, there are three smaller areas, separated from the larger. The largest of these is that forming the Long Green valley, which apparently is only a portion of the Dulany valley and Glenarm bodies, from which it is separated on the higher land by the overlying Wissahickon schist. The second area lies south of Taylor, and is apparently separated from the Green Run arm of the main mass by a strike fault. The third area is represented by a single cutcrop of very small extent, occurring beside the road just east of Glencoe station.

Greenspring valley.—The marbles of the Greenspring valley extend from west of the Reisterstown turnpike and the Western Maryland railroad eastward to the Northern Central railroad, where the valley broadens, reaching out into the various valleys already described. The marbles in this region are found in small outcrops, where they strike parallel with the axis of the valley and dip northward at a decreasing angle as one passes from the south and west to the limits of the overlying Wissahickon formation. The dip is, however, generally steeper than 45 degrees. As the limestone circles round the southwestern anticline the strikes change in conformity with the contour of the major fold, and the dip is uniformly away from the quartzite and beneath the Wissahickon schist lying to the west of Lake Roland. Between the eastern and western ends of the anticline the limestone is compressed within minor folds in the quartzite at Mount Wilson and in several places along Moores branch. It is lacking, however, in its normal position (between the quartzite and the Wissahickon) from a point 1 mile east of Cockeysville to the western limit of the fold, with the exception of the single exposure, already referred to, occurring at Mount Wilson. In the valley above Lake Roland the limestone is only exposed once or twice, as at the junction of Jones falls and Roland run. Such structural observations as can be made are in accord with the synclinal structure of this small southern offshoot of the Greenspring valley. The limits of the limestone south of the Greenspring valley are determined on the east by a north and south fault passing from Sherwood through Ruxton to Lake Roland and thence into the lowland above Mount Washington. The exposures of marble from Sherwood to Glenarm show relatively simple monoclinal dips to the northward, except in the region southwest of the Wissahickon, where this marble unites with that of the Dulany valley, and in the vicinity of Glenarm, where the limestones fold sharply around the upturned anticline of quartzite already described. At each of these points there is minor folding, and the local structure is much confused in its detail, although harmonizing well with the broader structure as here outlined. The exposures for the most part are poor and occur almost exclusively in small private openings, where the stone has been extracted for lime.

Dulany valley.—This valley, which extends for 5 miles northeasterly of Lutherville, with an average width of from 1 to 2 miles, shows numerous exposures west of the Gunpowder river, but is almost entirely lacking in the same from the Gunpowder to its easternmost limit. Enough observations, however, have been made to show that the limestone is here very flat, with several minor crests and folds extending parallel to the longer diameter of the valley, the limestone dipping beneath the Wissahickon on the north at a varying angle.

North of Merediths bridge, where the Jarrettsville turnpike rises from the limestone valley to the level of the plateau, the strike of the limestone changes rapidly through west and northwest to a little east of north, following the course of the Gunpowder river. From the vicinity of

Overshot run the strikes again change to west of north, following the course of the Gunpowder and Royston branch, the latter curving with the limestone as it wraps around the small anticline near Warren. The dip on the east side of Gunpowder valley is northeasterly under the Wissahickon, in all instances observed, but along the west side there seems to be some slight overturning, the limestones dipping at times to the westward beneath the quartzite, which normally lies below the limestone. The exposures in this offshoot from the main limestone valley are rather better than usual, and show with unusual clearness for Piedmont conditions the shifting stripes and dips due to the folding of the region. This is particularly true in the area northeast of Warren, which is discussed more fully at another place.

Worthington valley—Butler area.—The marbles which are so well developed in the valley between Lutherville and Cockeysville extend westward from the latter point along the south side of the northern anticlinal dome, widening about 5 miles west of Cockeysville into the Worthington valley, which is in reality the southwestern nose of the northern anticline, as already described. The exposures of limestone in the narrower portions of the valley are rather unsatisfactory, but show an east-and-west strike and a dip of 40 to 60 degrees away from the Baltimore gneiss and beneath the Wissahickon schists on the south. In the wider portion of the valley the dips become much less, reaching as low as 5 and 10 degrees. The strike also changes, as the limestone of the valley wraps around the anticlinal axis, from east to west and northwest and north to east of north. In this part of Worthington valley the natural exposures are few, but the solid rock has been exposed in many places by small quarries made for the extracting of limestone for agricultural purposes.

Extending northeastward from Worthington valley the limestone is found in three well defined bands forming narrow valleys. These different bands are representatives of the same formation brought to the surface again and again by the folding of the beds along the level of the present surface of the country. The dips are often steep and sometimes overturned, but the bands unite to form a continuous valley in their southwestern limits. The strike in every instance appears to be parallel to the valleys. The more southerly bands are separated by a synclinal of the overlying Wissahickon, and are in turn separated from the northernmost bands by a tightly compressed anticline exposing the Cambrian quartzite and the underlying Baltimore gneiss. These limestone areas do not extend east of the Northern Central railroad, and in only one instance are they found east of the Baltimore and York turnpike. The relations existing along their eastern limit are not determined with entire satisfaction. The areal distribution, dips, and strikes suggest that we have here the emergence of a syncline above the surface of the country, but the underlying quartzite which one would naturally expect to find bordering the limestone is absent, and the cause for this absence is not entirely evident. It is easily recognized in the field that the quartzite formation is thinning rapidly as one passes across the strike from the broad exposures in the hills south of Stringtown to the thinner development bordering the Butler-Belfast valley. Moreover, to the southward the limestone rests immediately on the Baltimore gneiss. These facts would seem to indicate that the quartzite did not extend over the entire area of the Baltimore gneiss beneath the marble at the time when the limestone was laid down. If this inference is true, it is easy to explain the non-occurrence of the quartzite on the eastern border of the limestone, and possibly to define the limits of deposition of the quartzite in this local area. Unfortunately, as is so often the case in the southern Piedmont, the exposures along contacts are very poor and frequently wanting at the critical point.

DISTRIBUTION OF WISSAHICKON FORMATION

The Wissahickon formation, which overlies the marble, occupies the remainder of the region, occurring in broad areas between the different limestone valleys already described. The schists and gneisses of the formation extend entirely around the northern anticline and occupy very much of the region between it and the southern anticline. The removal of the Wissahickon across the axis of the synclinorium along the course of the Northern Central railroad between Lutherville and Cockeysville separates the Wissahickon, however, into an eastern and western portion. The western representative of the Wissahickon, lying between the northern and southern anticlines and the Western Maryland and Northern Central railroads, forms a series of well rounded hills, which reach to the level of the plateau along their summits. The exposures throughout this region are poor, the material of the Wissahickon formation yielding a good soil and breaking down easily to a protecting mantle over the readily disintegrating garnet mica-schists. It is possible, however, to recognize that in this general basin are one or two minor folds, giving an anticline across the area a little south of the center and two minor synclinal axes just within the limits of the Wissahickon-Cockeysville marble contact.

The more eastern area of Wissahickon lying on either side of Dulany valley and extending thence northeast appears to be somewhat more complex. The rocks in the area about Loch Raven appear more gneissic and even approach the Baltimore gneiss in appearance, while the schists on the north side of Dulany valley in the vicinity of Blenheim differ somewhat from those exposed farther west. The change is due in part to the presence of a small area of intrusive meta-gabbro.

The dips and strikes, as is customary in the Wissahickon formation, are rather variable; but in their cumulative effect they show a syncline overturned to the southward in the vicinity of Loch Raven and a gentle normal syncline forming the ridge in the vicinity of the Jarrettsville turnpike. Farther westward in the high land between Royston branch and Green run the structure is more complex, and will be described in more detail when discussing the structure in the vicinity of Warren.

STRUCTURE

GENERAL CHARACTERISTICS

The structure of the Cockeysville marble area is not thoroughly understood without a consideration of its relations to the general structure of the eastern part of the continent.* As is well known, the general tectonic lines extend northeast from the south across Virginia until they reach the limits of Maryland, when the strike of the various formations is deflected to a more easterly position, sometimes even becoming east and west. This general easterly trend of the formations passes in a broad band, reaching from central Pennsylvania to the Atlantic, and gradually returns in New Jersey and New York to its original northeasterly trend. The Maryland area, and particularly that portion north of Baltimore, is in the concave side of this major fold, a fact which explains certain of the structures found within this area, which appear to be somewhat unlike those described from other parts of the Piedmont and which doubtless led the late Professor Williams to an accentuation of the oval-shaped figures for his different formations. The occurrence of the various forces involved in the curvature of the general structure have produced locally within the Maryland area conditions favorable to torsional deformation, since the lines of distribution of the forces are not parallel, but slightly inclined to each other. It is for this reason, in part, at least, that the various folds, which are usually very long and narrow throughout the Appalachian region, are here rather short and dome-like, with intervening areas of less compressed folding. The effects of these differences in conditions will be brought out more fully in discussing the faulting.

The structural character of the Cockeysville region has already been given in describing the areal distribution of the various formations, but it is well to recall the fact that it consists essentially of anticlinal domes separated on their sides by synclinoria, the axes of which run parallel to the general structure of the larger folds, which are found farther to the north and west, where they partake of the structural characteristics of the eastern portion of the continent.

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* These are more fully discussed by the senior author in the preceding paper, pp. 334-335.

FOLDING

The folding of the rocks within the region, as opposed to the minor textual features, such as crinkling, cleavage, and schistosity, may be broadly characterized as consisting of a series of open folds of simple character, the individual portions of which are marked by numerous sharply compressed smaller folds, with axes parallel to those of the general structure.

The character of the folding is most readily seen by an examination of a few exceptional localities and the areal distribution of the various formations involved. It is not easy, usually, to recognize the structural characteristics from given exposures, though these may generally be detected within the individual formations when the general structural lines have been determined. This fact has rendered most attempts to work from the more detailed to the more general barren of structural results.

The simple open character of the major folding is well indicated in the structural sections across the face of the accompanying map, but the detailed complexity of this exceedingly intricate region is only shown diagrammatically.

A feature of the folding which should not be overlooked is a tendency toward unsymmetrical folds and often to overturned folds. The unsymmetrical folding seems to be a property characteristic for the entire regions, though never very sharply brought out, while the overturned fold is a feature of local development, as along the south border of the southwest anticlinal dome, where there is an intertonguing of the quartzite and marble, with dips indicating overturned folds. This overturning is also shown in many minor folds of the northern anticlinal dome, but the similarity of the beds and the poor exposures in this area render it difficult to do more than decipher the local structure here and there. The intervening well cultivated fields or soil-clad forested areas make it impossible to carry minor structures across the folds.

FAULTING

The faulting in the area, so far as it is seen, introduces one of the most interesting structural features noticed and brings out the influence of the continental structures on this region. Although many small faults of slight throw may be detected during the course of field study, only three faults of considerable magnitude have been noted, and these are not very clearly shown except by the areal distribution and contiguous structural details. These faults, as shown on the general map, lie in a curved line passing from the Little Gunpowder near Hess to the valley of Jones falls in the vicinity of Mount Washington. They are all in the nature of thrust faults, but the almost complete absence of anything approaching contacts renders it difficult to demonstrate this fact. There

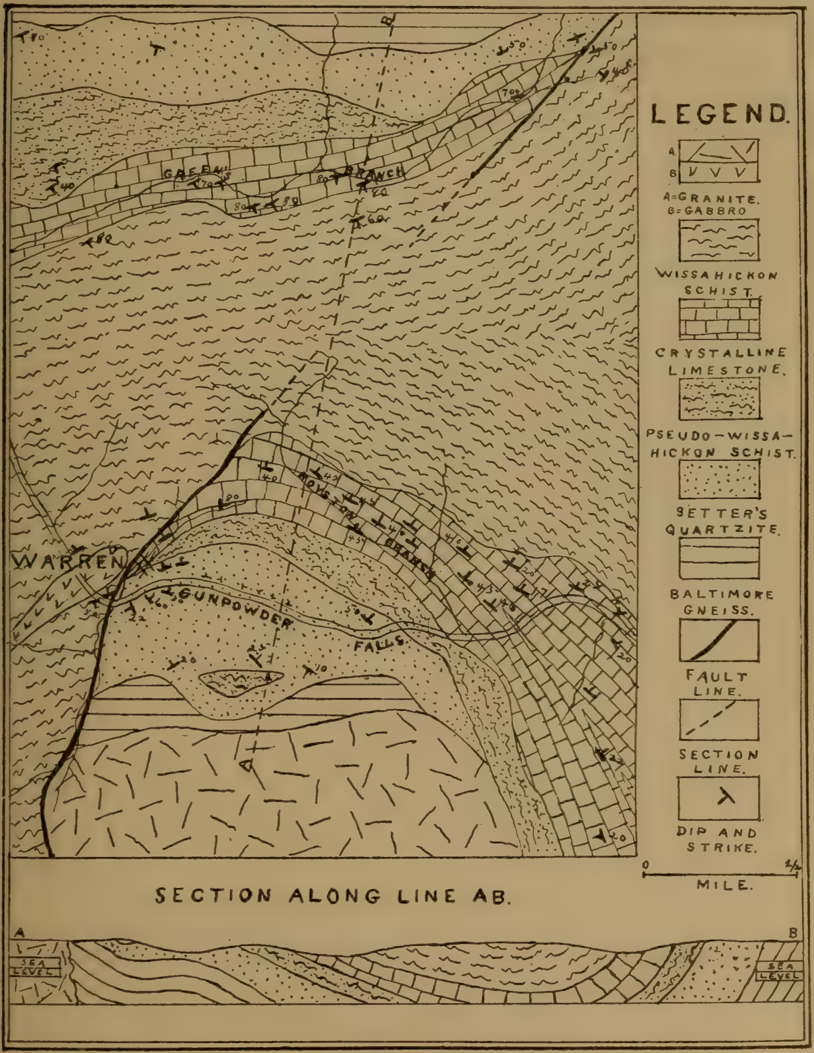
LEGEND.
A
B
A=GRANITE.
B=GABBRO
WISSAHICKON SCHIST.
CRYSTALLINE LIMESTONE.
PSEUDO-WISSAHICKON SCHIST.
SETTER'S QUARTZITE.
BALTIMORE GNEISS.
FAULT LINE.
SECTION LINE.
DIP AND STRIKE.
0
1/4
MILE.
WARREN
GREEN BRANCH
GUNPOWDER FALLS
SECTION ALONG LINE AB.
A
B
SEA LEVEL
SEA LEVEL

Figure 1.—*Map of Vicinity of Warren.*

is, moreover, a torsional feature in these faults which is of especial interest. The thrust at the northern end of the fault is slightly to the eastward, as in the vicinity southwest of Hess, where the Setters quartzite may be found above the Wissahickon and limestone if the latter is present. Along the central and southern portions of the fault line, however, the thrust is westward. The relationships may be most thoroughly studied in the valley of the Gunpowder at Warren, where it is quite clearly shown that we have a somewhat complex anticline plunging to the northward with a compressed fold in a line passing through the town of Warren.

The anticlinal character of the folding is evident (figure 2) east of Warren near the mouth of Royston branch, where the Gunpowder flows in a gorge cut through the Setters quartzite and "pseudo Wissahickon" (the garnetiferous upper portion of the quartzite formation) and Cockeysville marble to the contact between the latter and the underlying Wissahickon, which it follows southward to Dulany valley. The strikes and dips as shown in the valley of Royston branch indicate at this point a northward plunging anticline, the west limb of which is replaced by the fault under discussion. The Wissahickon schists may be traced continuously around the anticline to the Gunpowder river immediately west of Warren bridge, where they are found striking to the south and dipping to the west or east, as the case may be. Near the quartzite on the south side of the Gunpowder the strike is southwesterly, and the dip is toward the east as a result, apparently of the overriding of the quartzite at this point. In the stream bottom beside the road leading from Warren to Cockeysville on the line of the fault is a recemented breccia, which indicates a portion, at least, of the fault zone.

The structural features of this locality indicate that the forces at work were northwest and southeast, and that the thrust, which here is slight as compared with that farther south, carried the Baltimore gneiss, quartzite, and marble across the Wissahickon formation.

The structural features along the southward continuation of this fault are much obscured by the intrusion of a granite mass which forms the eastern boundary of the Wissahickon and probably occupies the eastern side of the fault, where one would naturally expect the Baltimore gneiss if there had been no granitic intrusion.

The southern fault, which extends from near Lutherville to south of Mount Washington, is similar in character to that already described about Warren, but much more pronounced.

The accompanying sketch map* (figure 2) of the valley of Jones falls between Rockland and Hollins, two stations on the Northern Central railroad, shows in detail the complexity of the structure in this area as well as the observations on which the present interpretation is based.

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*The relative position of the detailed maps may be indicated approximately by placing the southwest corner of the neat line of figure 1 over the northeast corner of figure 2. Both figures oriented north and south.

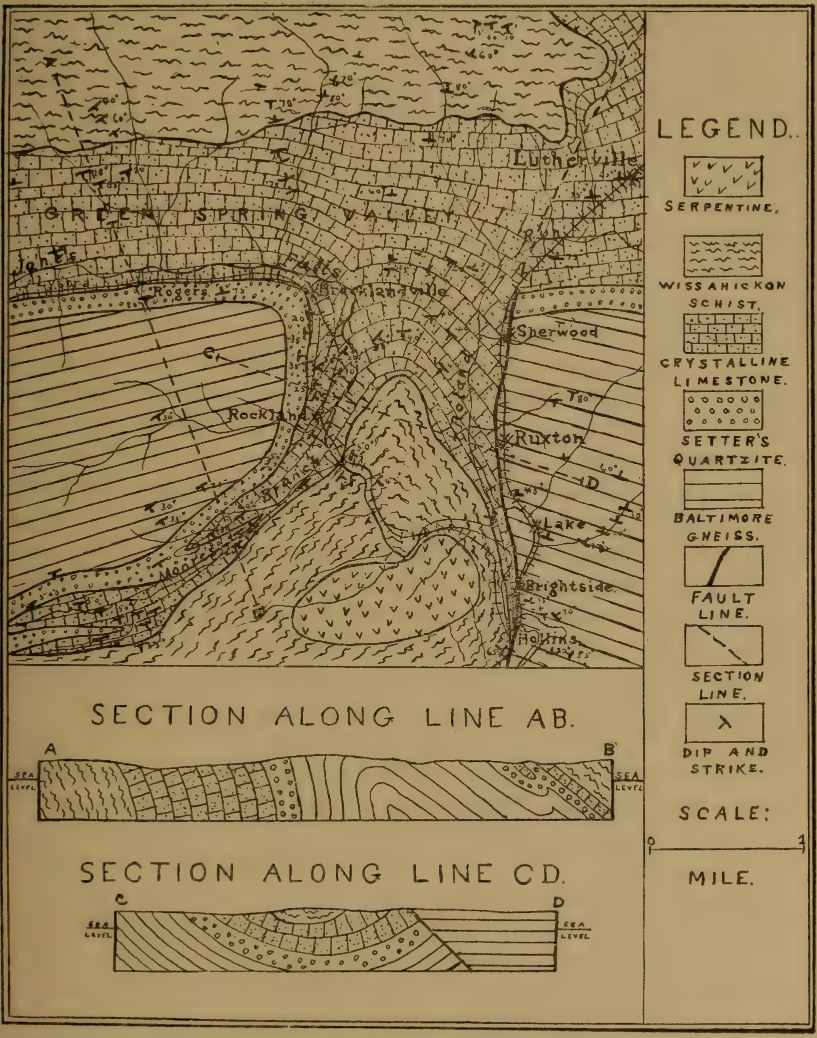
Lutherville
GREEN SPRING VALLEY
John's
Falls
Run
Rogers
Brooklandville
Sherwood
C
Rockland
Ruxton
D
Lake
Brightside
Hollins
Moore
LEGEND.
SERPENTINE.
WISSAHICKON SCHIST.
CRYSTALLINE LIMESTONE.
SETTER'S QUARTZITE.
BALTIMORE GNEISS.
FAULT LINE.
SECTION LINE.
DIP AND STRIKE.
SCALE:
0
1
MILE.
SECTION ALONG LINE AB.
A
B
SEA LEVEL
SEA LEVEL
SECTION ALONG LINE CD.
C
D
SEA LEVEL
SEA LEVEL

FIGURE 2.—*Map af Vicinity of Rockland.*

On the west is the eastern end of the southwestern anticlinal dome already described, and on the east the southerly extension of the fault under discussion. Earlier work in the region led Doctor Williams to interpret the eastern termination of the western anticline as a fault complementary to the fault recognized by him and the authors on the eastern side of the valley. It was supposed by Professor Williams that this valley represented a faulted block of limestone. That such is not the case is well shown by observations recorded in the accompanying map, where the strikes and dips may be traced with constantly changing azimuth about the nose of the anticline from Rogers station to the southwestern corner of the sketch map. The structural details in the center of the valley in the limestone indicating a southward plunging syncline also corroborate the later interpretation. The original view evidently arose from the failure to recognize the difference between the overlying Wissahickon and the underlying Baltimore gneiss.

Although no exposures are found along the actual fault line between Sherwood and Brightside, the sharp divergence in strike and dip as well as the difference in character of the rock leaves no doubt as to the occurrence of a fault at this point. The ends of the various beds of the Baltimore gneiss strike northwesterly against the limestone and Wissahickon, which have a more southerly trend and a dip to the westward.

The westward thrust of the eastern anticline widens very perceptibly (see general map, plate 65), the distance between the quartzite areas representing the limbs of the anticline. They are fully twice as far apart as in the corresponding anticlinal dome on the western side of the valley. If the foregoing parts of what appears to be a single fault zone be regarded as separate faults, they may be characterized as follows: The northernmost fault differs from each of the others in some particulars and in other particulars is like them. Like the Warren fault, it occurs parallel to the strike of the major anticlinal dome, but, unlike both the Warren and Ruxton faults, the thrust is toward the southeast. This difference in the direction of the thrust within the distance of a few miles would be a serious matter to explain without a knowledge of the continental structure to the westward. With these facts at hand the relationships become clearer. All three of the faults show the older, more crystalline, and more competent Baltimore gneiss thrust over the younger and more yielding marbles and Wissahickon schist. In the faulting the quartzite is associated with the underlying gneiss, with which it is lithologically very similar. The difference in thrust at the different points may be produced by the slightly divergent lines of force which have produced compression and local glancing blows resulting in a small amount of contortion. Thus on the north the Baltimore gneiss is shoved southward and on the south it is shoved northward, while in between is a less marked faulting, which partakes of the westerly thrust from the south, but is here not as strongly marked.

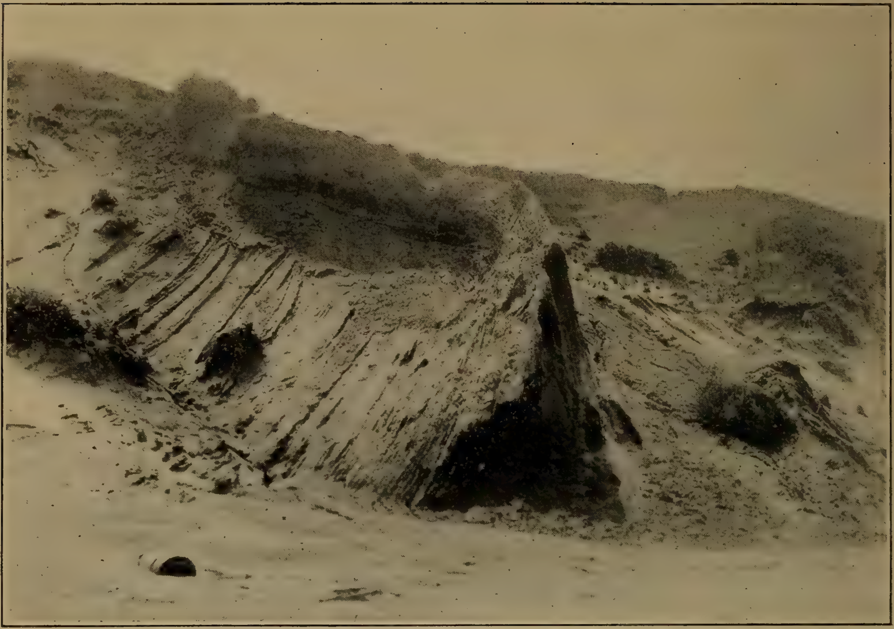

FIGURE 1.—JACOB SAND OVERTURNED AND RECUMBENT ON HEROD GRAVEL; GARDINER ISLAND, NEW YORK

Gardiner clay at right of part of fold shown

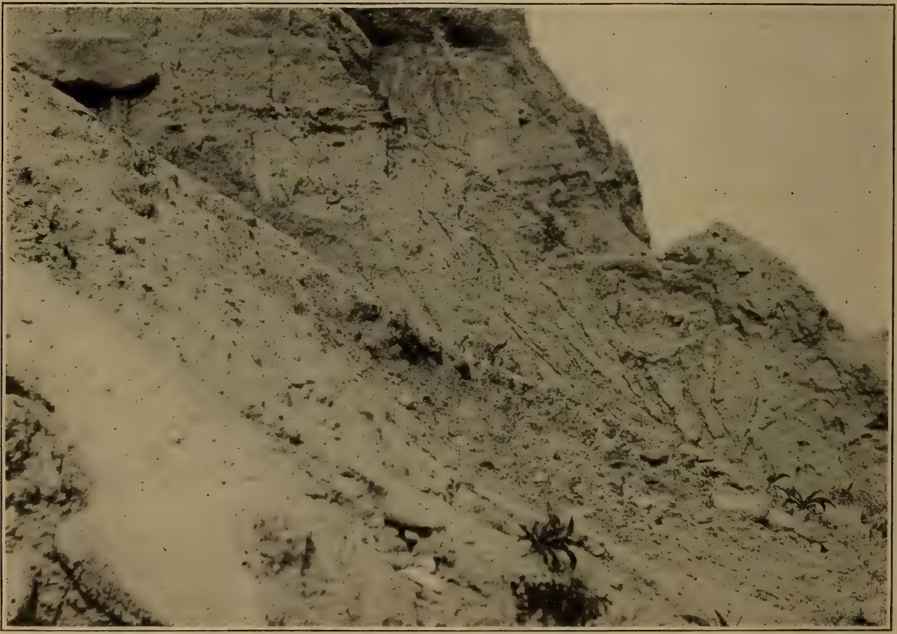

FIGURE 2.—SEMI-STRATIFIED TYPE OF MONTAUK DRIFT; MONTAUK POINT, NEW YORK

JACOB SAND AND MONTAUK DRIFT

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GEOLOGY OF FISHERS ISLAND, NEW YORK*

BY MYRON L. FULLER

(Presented before the Society December 31, 1904)

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Location and General Relations

Fishers island, although belonging to New York state, is situated off the coast of the eastern portion of Connecticut, the western end being 7 miles southeast of New London and the east extremity within 2 miles of Napatree point, at the extreme southwest corner of Rhode Island (figure 1).

The island is a little less than 7 miles in length and has an average width of somewhat over half a mile, although near Clay point and west of West harbor its width is upward of a mile (figure 2). It lies in the prolongation of the structural axis of Orient point, Long island, which axis, after passing through Plum and Fishers islands, is recognized along the ridge extending eastward from Watch hill, Rhode Island. Its posi-

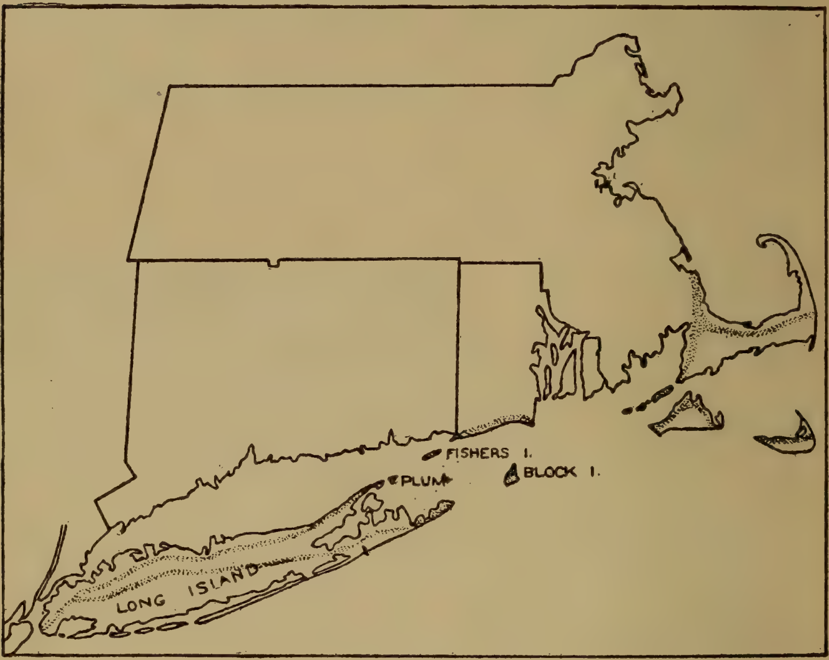

FIGURE 1.—*Index Map of Fishers Island.*

Showing its location and relation to the principal moraines of the Wisconsin stage.

tion is masked throughout by a mantle of drift of the inner Wisconsin moraine. The island has the general sinuosity of coastline and inequality of topography which would be expected to result from the partial submergence of an irregular ridge. Such, in fact, has doubtless been its origin.

TOPOGRAPHY

The topography of Fishers island, like its coastline, is highly irregular, its eminences being without apparent system other than the linear arrangement due to the shape of the island. Some of the hills, like those along Isabella beach, have a well marked northeast-southwest trend. At other points, as southwest of Chocomount cove, the hills occur as isolated knobs, or again, as between Hay and West harbor, they occur as somewhat general but broken elevations.

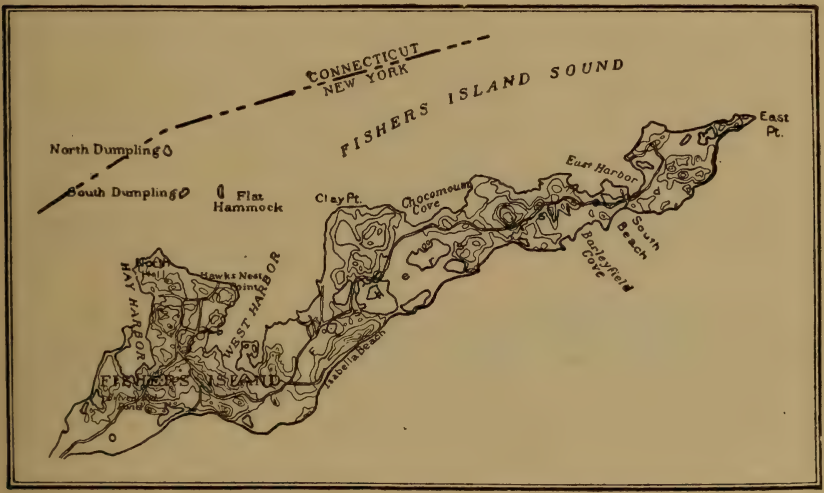
CONNECTICUT
NEW YORK
FISHERS ISLAND SOUND
North Dumpling
South Dumpling
Flat Hammock
Clay Pt.
Chocomount Cove
East Harbor
East Pt.
South Beach
Barleyfield Cove
HAY HARBOR
Hawks Nest Point
WEST HARBOR
FISHERS ISLAND
Isabella Beach

Figure 2.—*Topographic Map of Fishers Island.*

Scale about 2 miles to an inch; contour interval, 20 feet.

The general aspect of the topography is decidedly morainal—an appearance which is heightened by the presence of a considerable number of large erratic boulders. An analysis of the topographic features in the field, however, shows that, while there are many minor knobs and numerous basin-like depressions which are sometimes of considerable size and contain ponds many acres in extent, the morainal features are, on the whole, mainly superficial, the broader lineaments of the landscape belonging clearly to an older topography, which in part appears to have been due to subareal erosion, especially at the western end of the island and near Clay point.

At other localities, as at the Isabella Beach hill and the hill forming the headland three-quarters of a mile to the northeast, the topography is more puzzling, and only after the unraveling of the geology was it determined that these hills were primarily constructional in form, representing in reality great anticlines in the Pleistocene sediments.

Some of the depressions occupied by ponds are evidently true kettles, representing the position of detached ice masses, which later become surrounded or buried by glacial outwash, but other basins appear to be due to the obstruction of older valleys by loose materials shoved up by the last ice-sheet, or to the excavation of shallow basins by its erosive action. Many of the more or less inclosed coves which occur along the coast of the island represent similar features which have been partly submerged.

The morainal topography is not confined to any one part of the island, but is most marked along the north shore, where the knobs and kettles are not only more conspicuously developed, but where erratic boulders are present in the greatest numbers. On the south side, while morainal features are not lacking, the topography commonly shows smoother and more rounded outlines. The difference is evidently due to the fact that the ice during the deposition of the morainal materials, which belong to a retreated stage of the Wisconsin, reached in general only part way across the island, the south shore topography showing to a greater or less extent pre-Wisconsin forms slightly modified by the overriding ice during the maximum advance when the ice margin stood at Block island or beyond.

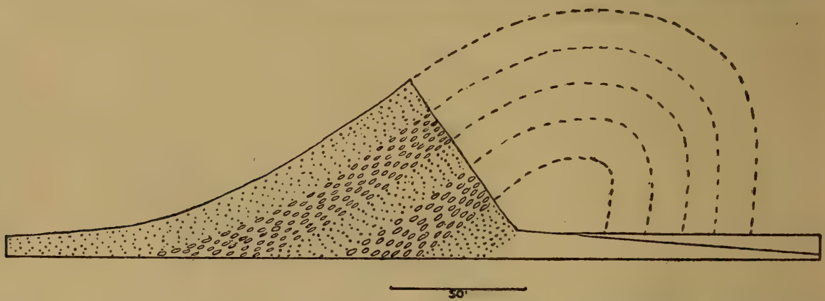

FIGURE 3.—*Section through Hill Three-quarters of a Mile Northeast of eastern End of Isabella Beach.*

Showing anticlinal structure of hill and the extent of marine erosion.

Topographic forms due to wave action are of relatively slight importance. In general the bluffs are low, and erosion is only active in times of especially severe storms. Usually they are covered by talus slopes, which effectually mantle the outcropping strata. At Isabella beach and again at the point three-quarters of a mile to the north the bluffs are steep and clean. The exposure at the latter point is of special interest, as it affords a basis for calculating the amount of erosion which has taken place since the sea reached the original southern base, the position of which, owing to the constructional origin of the hill, can be readily determined. In figure 3 is given a section through the hill showing its anticlinal structure and former extent.

A few small spits have been built out at a number of points on the coast of the island, and barrier beaches have been formed by the waves across some of the small reentrants, giving rise to certain of the ponds, but at other points, as in the vicinity of Silver Eel pond, the barriers are composed of boulders and appear to be in part, at least, the work of glacial ice.

GEOLOGY

GENERAL CONDITIONS

Fishers island falls in line with the inner or later of the two Wisconsin moraines (figure 1), and as it exhibits a kettle and knob topography and has a surface of till, or at least a sprinkling of large erratic boulders over considerable areas, it has generally been regarded as a morainal island of late Wisconsin age. A careful study of the composition and structure of the deposits, however, brought out the fact, which was already suspected from the topography of the island, that the Wisconsin drift forms a thin superficial mantle resting on folded and eroded Pleistocene beds of a much earlier stage.

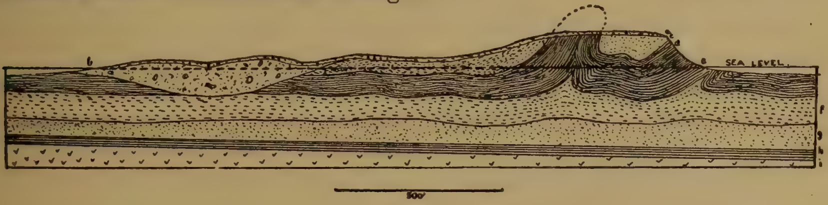

FIGURE 4.—*Generalized Section of Fishers Island.*

a, Wisconsin till; *b*, Montauk drift; *c*, Herod gravel; *d*, Jacob sand; *e*, Gardiner clay; *f*, Jameco gravel; *g*, Mannetto gravel (?); *h*, Cretaceous clay; *i*, light-gray granite.

In working out the geology of the island, cliff sections furnished the greater part of the information, although the big clay pit on the east side of West harbor and an artificial section near the steamboat landing on the west side of West harbor afforded important data. In the field work all prominent bluff exposures along the coast were visited, the highways traversed, and such artificial sections as could be found examined.

The field work brought out the fact that not only are the greater part of the deposits of pre-Wisconsin age, but that in the upbuilding of the island a considerable number of stages, including both those of deposition and erosion, have been represented. Of these at least three may be recognized in the portion of the deposits above sealevel, the first being marked by thick deposits of dark-colored clay, the second by the deposition of glacial gravels, followed by the deposition of till or by a period of folding, and the third by a long period of erosion. These events are recorded by the succession of strata and unconformities, as illustrated by the accompanying section (figure 4), and will be described in detail in the following pages, beginning with the lower or oldest bed.

CHARACTER AND HISTORY OF THE DEPOSITS

Granite foundation.—The formations exposed above sealevel on Fishers island are all of Pleistocene age, but in the Ferguson well, drilled by C. L. Grant, certain older materials were encountered.

Record of Ferguson well

	Feet
Gravel, boulders, and sand	0 to 260
Blue clay............	260 to 281
Light-gray granite.........................	281 to 485

In character the granite corresponds to the rock which is extensively quarried at Westerly and vicinity in Rhode Island, a few miles to the northeast, and with which it may be genetically connected.

The record indicates a slope of the rock surface of about 100 feet to the mile from its outcrop along the Connecticut shore to the well, which is about the same as that found in western Long island and along the Atlantic coastal plain generally. The rock surface, judging from its character elsewhere, is doubtless undulating, but of this there is no local evidence. The tilting of the surface, which had previously been nearly horizontal, probably commenced about the beginning of the Cretaceous period, and doubtless continued during the deposition of the Cretaceous and subsequent deposits until its present inclination was reached.

One of the interesting features brought out by the well is the occurrence of fresh water in the granite at a depth of 328 feet, or about 300 feet below sealevel. As the overlying drift yielded salt water, it is not likely that the supply came from the island itself, but rather from the mainland to the north, being conveyed along north-south joints or possibly faults. The overlying bed of blue clay doubtless serves as a capping, preventing both the escape of the fresh water and the ingress of the salt.*

Basal blue clay.—Resting on the granite, as indicated in the record of the Ferguson well, with its base about 260 feet below sealevel, is a bed of "blue clay" 21 feet in thickness. No samples of this clay have been seen, but the fact that it rests on the granite instead of on a thick series of glacial gravels, as does the only known Pleistocene clay of the region, points to its probable Cretaceous age. If so, it doubtless accumulated soon after the uplift and seaward tilting, which has been described as beginning in early Cretaceous times, and which increased the gradient of the streams, with the result that they rapidly attacked the weathered surface of the granite, carrying the resulting materials to the sea when they were deposited as the clays and sands so characteristic of that time.

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*While unusual, this lateral transmission of water through joints in rocks covered with clay is not unknown elsewhere, the writer having worked out an example of such transmission for a distance of more than 20 miles in southeastern Michigan.

As originally deposited the Cretaceous beds have usually been considered to have formed a belt along the southern New England coast overlapping the Connecticut and Rhode Island shores. Erosion, however, subsequently so reduced these beds that the only remnants probably remaining in early Pleistocene times were those in the western third of Long island and possibly those on western Marthas Vineyard. On Block island the Cretaceous beds were almost certainly below sealevel until uplifted by the folding to be subsequently described, and it is not impossible that such was also the case at Marthas Vineyard, although it is more probable that the Cretaceous at this point stood somewhat above sealevel even before the folding.

Mannetto and Jameco gravels.—In the record of the Ferguson well (page 372) the materials from the surface to a depth of 260 feet, or to about 240 feet below sealevel, are given as "gravel, boulders, and sand." In it there is no mention of the thick, tough clays which occur to a thickness of perhaps 100 feet in the clay pit, and which are found above sealevel at other points on the island. As no driller could fail to recognize this clay, it is evident that it is cut out at the point where the well is located, probably having been eroded by ice action, as explained on page 370. The "boulders," except those in the thin surface layer of Wisconsin till, can come only from the much older till known as the Montauk drift, which probably has a thickness of not over 100 feet. This would leave about 160 feet of gravels and sands between the old drift and the basal blue clay (Cretaceous?), to which must be added the unknown thickness of gravels removed by the same erosion that cut out the thick, dark-colored clays. This is a considerably greater thickness than is normally found on Long or Block island, where the corresponding gravels belong to a single formation—the Jameco—which on Block island, the nearest point at which they are exposed, have a thickness of not over 50 feet. Even if twice this thickness was present on Fishers island, there would still be about 50 feet of materials remaining unassigned.

This interval may in part be made up of Cretaceous sands and gravels, but as these are commonly distinctly different from the glacial materials and are commonly recognized by drillers, it seems probable that the materials are all Pleistocene.

Resting on the Cretaceous in western Long island, and coming between it and the Jameco gravels with the general relations shown in figure 5, is a series of old gravels of somewhat distinctive characteristics.

These gravels, which are the oldest Pleistocene beds yet recognized in the region, consist of moderately fine rounded fragments of quartz, with a slight admixture of deeply weathered granite pebbles, having originally a thickness of some 500 feet. They rest unconformably on the Cretaceous and are overlain unconformably by the more granitic beds designated as the Jameco gravels and described on a subsequent page. To the lower and older gravels the term Mannetto,[*] from Mannetto or High hill south of Huntington, Long island, where the beds are best exposed, is applied.

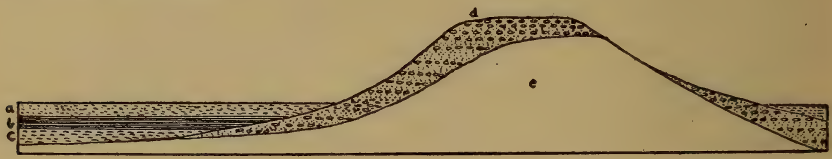

FIGURE 5.—*General Relations of Cretaceous Beds and the Mannetto and Jameco Gravels.*

The area shown is the region of the West or Mannetto hills on western Long island. *a*, Wisconsin and other post-Gardiner sands; *b*, Gardiner clay; *c*, Jameco gravel; *d*, Mannetto gravel; *e*, Cretaceous.

The Mannetto beds are easily recognized by their quartzose character and by weathered granitic pebbles, which can usually be crushed by the fingers or by a slight blow of the hammer. They were deposited during a period of depression when the land in western Long island stood about 300 feet lower than at present, the materials being derived from the wash from an ice-sheet which obtained much of its material from the Cretaceous deposits over which its margin advanced. The deposition followed a long period of erosion in late Tertiary times, during which all Tertiary and much of the Cretaceous materials were removed.

The Mannetto beds have not been seen anywhere east of Mannetto hills, but on Fishers island, as has already been pointed out, the interval between the dark glacial clay (Gardiner) and the basal blue clay (Cretaceous) is considerably greater than is required for the Jameco gravels; hence it is not improbable that a considerable thickness of Mannetto beds may be present beneath the island and having the relations shown in figure 4.

The term "Jameco gravels," which is named from the village of

---

[*] Proposed in manuscript discussion of the geology of the underground waters of Long island by A. C. Veatch.

Jameco, on western Long island, at the point where the deposits were first recognized in a deep well, is applied to the stratified glacial gravels resting unconformably on the Mannetto beds and overlain by the Gardiner clays.* They commonly vary from 40 feet upward to possibly 100 feet in thickness, and are rich in granitic material, which is only moderately weathered. These gravels unquestionably underlie the clays of Fishers island, or, where these are cut out, occur beneath the old Montauk drift. They were not seen anywhere in the bluff sections, and presumably do not occur above sealevel, but undoubtedly form a considerable part of the "gravel and sand" recorded in the Ferguson well.

Gardiner clay—Use of term.—This term, which is applied to the thick clay bed overlying conformably the Jameco gravels throughout Long and the other New York and New England islands, takes its name from Gardiner island, near the east end of Long island, where it is strongly developed in many of the bluffs. Its position in the Fishers Island section is shown in figure 4.

Conditions of deposition.—The moderate submergence which characterized the period of deposition of the Jameco gravels continued without material change during the accumulation of the basal portion of the Gardiner clay, the actual altitude of the land apparently being slightly higher than at present, the normal position of the clays, except when brought up by folding, being somewhat below the present sealevel. The deposition appears to have taken place during a true interglacial period, as is shown by the absence of recognizable glacial materials and by the presence of a fossil fauna (and on Long island and elsewhere of lignite), indicating a period of sufficient length to permit the reoccupation of the former glacial waters by a fauna characteristic of temperatures not greatly different from those of the Maine coast at the present time. The thickness of the clays themselves, taken in connection with the known slowness of accumulation of such materials, likewise points to a period of great length and one which is more compatible with an interglacial stage than with a temporary retreat.

The lignitic clays of western Long island appear to have accumulated as marsh deposits bordering the old land masses; but in eastern Long island and on Plum and Fishers islands the clays seem to have been offshore deposits.

The source of the materials of which the clays are composed is somewhat difficult to determine. On western Long island, where the latter reach their maximum thickness, they may be conceived to have been derived from the erosion of the Cretaceous deposits from which the mantle of Mannetto gravel had been eroded and which there rose well above sealevel. In eastern Long island, however, and eastward at least as far as Marthas Vineyard it seems improbable that the Cretaceous beds stood much, if any, above sealevel, and it is unlikely that they furnished any great proportion of the materials of the Gardiner clay. In eastern Long island and on Plum and Fishers islands the color is suggestive of a derivation from the Triassic area of Connecticut, the silt being brought to the ocean by the Connecticut river, which may be conceived as having emptied eastward at the time. The amount of clayey sediment now carried by the New England rivers is extremely slight, and the accumulation of from 30 to 150 feet of clays over so wide an area would, under the present condition, require a time interval of great length. It is not impossible that the land, although low in the vicinity of Long island, may have been somewhat elevated to the north, in which case erosion would be facilitated and relatively large amounts of silt furnished. Of such an elevation, however, the writer knows of no other evidence, unless the cool climate is to be taken as indicating the existence of elevations of some importance in the near vicinity—a not very reasonable supposition.

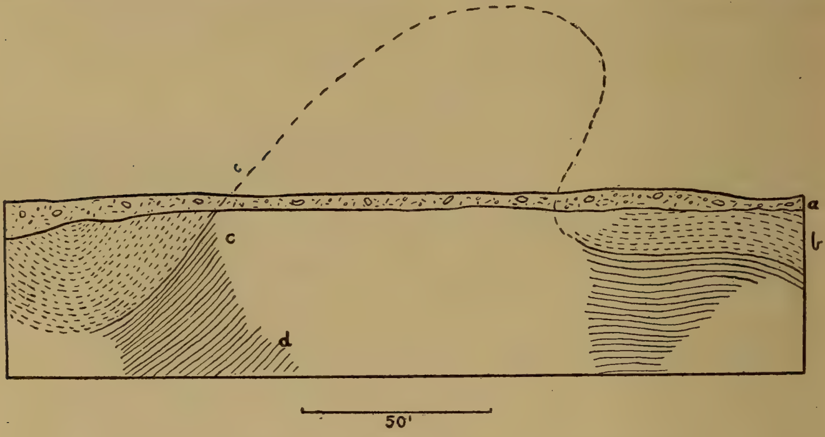

Figure 6.—*North-south Section across Clay Pit on Fishers Island.*

Showing exposures as seen in June, 1904, with interpreted structure. *a*, Wisconsin till; *b*, sand and granitic gravel (Herod); *c*, brownish sandy clay interlaminated with sand (Jacob); *d*, dark gray to almost black plastic clay (Gardiner).

Composition of the clays.—In the pit where they are best seen the clays are probably exposed to a thickness of 40 or 50[*] feet in what appears to be a closed and partly overturned anticline (figure 6). The clay pit was started in a valley where the clay showed at the surface, but has now been worked back until 10 to 30 feet of till or gravel have to be stripped off. The outer or upper part of the material worked at the pit is a brownish sandy clay interlaminated with sand and perhaps 40 feet in thickness. The remainder, including the part now worked, is a dark-gray, blue to nearly black plastic clay, with a slight brownish tinge, almost identical in appearance with the thick clays at Nashaquitsa cliffs, on Marthas Vineyard, and at Highland light, cape Cod. No pebbles could be found by the writer except in the lowest part of the clay exposed, where a lens of granitic gravel was seen, possibly due to the incorporation of some of the underlying Jameco materials. No fossil shells or leaves are reported. Some rounded clay concretions occur, and dendritic markings are found between some of the laminæ. At Isabella beach brownish and gray clays are seen in alternating laminæ, while a greenish-gray clay, probably representing a weathered phase of the Gardiner, is seen three-quarters of a mile to the north.

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[*] The thickness of the entire series, which includes the Jacob sands, which are here rather clayey, is from 75 to 100 feet.

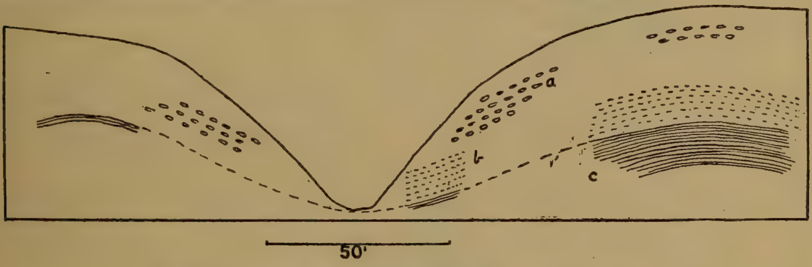

FIGURE 7.—*Northeast-southwest section along Isabella Beach.*

Showing, *a*, Herod gravels; *b*, Jacob sands, and, *c*, Gardiner clay. As elsewhere throughout the island, there is a noticeable agreement between the topography and the geologic structure.

Details of occurrence.—The best exposures of the Gardiner clay, as has been indicated, are at the clay pit where the section shown in figure 6 is exposed. The dip at the pit commonly averages 45 degrees to the north, pointing to a fold of considerable magnitude and indicating conditions of folding much more marked than was supposed by Dr H. Ries, who reported the disturbance to extend only to a depth of 20 to 30 feet.* That the folding is essentially superficial is likewise believed by the present writer (figure 4), but, as indicated by figures 3, 6, and 7, which are drawn to scale, is certainly much greater than the figures quoted. Besides the main folding there are many minor contortions which appear to be due to movements of the clay layers over one another.

Besides the clay pit there is only one point where the Gardiner clay is well exposed, the clayey sands in the lower portion of the high bluff on the south shore just south of West harbor belonging to the Jacob sands. The exception is at Isabella beach, where, in the sections represented in figures 7 and 8, up to 20 feet of clay is exposed. In the section shown in the latter figure the clay is 12 feet in thickness and consists of alternating layers of gray and chocolate silts, weathering to a somewhat darker color and dipping about 45 degrees to the north. At the locality of figure 7 the clays are exposed to a thickness of more than 20 feet, and occur in a broad trough coincident with a surface valley. In both localities they are overlain by grayish clayey sands into which they grade.

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* Bull. New York State Mus., no. 135, 1900, p. 603.

Clay is said to have once outcropped near Clay point, on the north shore of the island, but there is now nothing but Wisconsin till to be seen in the low bluffs in that vicinity. In the base of the bluff forming the headland three-quarters of a mile northeast of the north end of Isabella beach there is exposed a few feet of greenish-gray clay, free from pebbles and similar to parts of the Gardiner, but its relations could not be determined (figure 9). At no other points was clay seen, the hills apparently being composed essentially of sand and fine gravel. Any storm, however, is liable to materially alter the bluff conditions, and if the clay is above sealevel it may be exposed at any time.

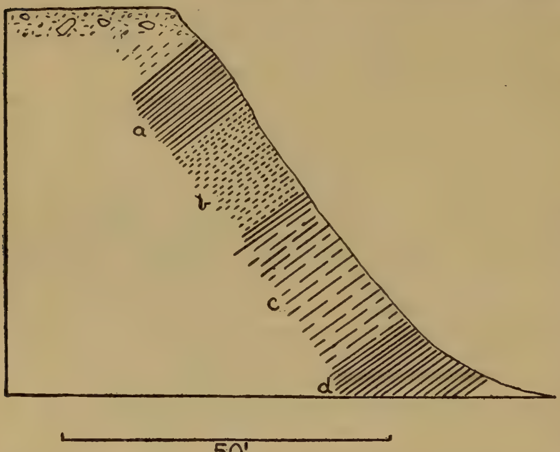

Figure 8.—*North-south Section through the Bluffs at Isabella Beach.*

a, grayish sandy clay; *b*, gray clayey sands; *c*, clayey sand weathering light grayish green; *d*, clay with alternating gray and chocolate layers weathering dark.

Jacob sands—Use of term.—This term is applied to the fine gray sands or the equivalents which overlie the Gardiner clay on Long island eastward to the New England islands and cape Cod. The name is taken from Jacob hill, a high point on the north shore of Long island 8 miles northeast of Riverhead, near which the sands are well exposed.

Conditions of deposition.—Whether the gradual change from plastic clays to the exceedingly fine, clay-like, quartz sands of the Jacob formation was due to an uplift, so that the water became shallow enough for semi-littoral conditions to prevail, whether the change was due to the deposition of the finer materials from the outwash of an advancing ice-sheet, or whether it was due to a combination of the two factors can not be definitely stated. The fact that the Jacob sand, like the Gardiner clay, gave place in turn to coarser materials, first sand then gravel and finally the Montauk drift, would make plausible the supposition that it was the supply of new materials by the advancing ice that brought about the change. Elevation of the land, however, is often thought to have accompanied ice invasions, and it may be that such was the case in the present instance. Nothing in the way of an unconformity which could be referred to stream erosion has been noted at this horizon. The unconformities cutting through Herod gravels, Jacob sands, Gardiner clays, etcetera, are such as might readily have been produced by the ice of the Montauk invasion; hence it is improbable that the land was uplifted above sealevel. On the contrary, the thickness of the series of deposits, including the Jacob sands, the Herod gravels, and the Montauk drift, all of which accumulated beneath sealevel, seems to indicate a progressive subsidence, since the Gardiner clays at the start were nearly at sealevel. It is not unreasonable to suppose that the change of material marking the beginning of Jacob deposition took place as soon as the advancing ice-front reached the headwaters of the Connecticut and discharged a portion of its drainage down its valley. Under such conditions it would only be the light materials which would be borne to the mouth and out into the sea. The amount of materials, if the supposition as to origin is correct, would indicate a very slow advance, since the Jacob sands reach a thickness of at least 40 feet on Fishers island.

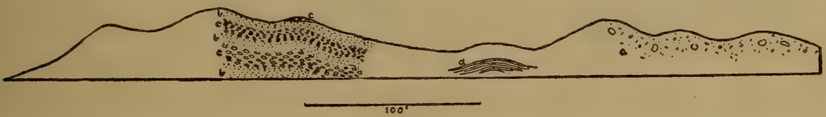

FIGURE 9.—*Section at Headland Three-quarters of a Mile Northeast of North End of Isabella Beach.*

a, till; *b*, gray sand; *c*, clayey gravels; *d*, greenish-gray clay.

Character of the sands.—The Jacob sands are not sharply separated from the underlying Gardiner clay, although the transition from one to the other usually occupies but a few feet. The change begins with the introduction of a few sandy laminæ into the clay, these rapidly becoming more numerous and of greater thickness until they take on the character of beds of exceedingly fine sands, almost quartz flour, but in which numerous grains of white mica and other particles of darker minerals may be seen. In color they commonly vary from a very light gray to yellowish and buff tints, but where laminæ of true clay are present they may be stained externally to a reddish tinge. They are always clearly stratified, although individual beds several feet in thickness, appearing structureless to the eye, are sometimes encountered. When wet they are often somewhat plastic, but lack the toughness of true clay, and are always decidedly gritty to the teeth, and usually to the touch. Nevertheless they so partake of the characteristics of the Gardiner clay that they are readily mistaken for it at first sight. They appear, however, to mark a distinct change in conditions, and hence are made a separate formation. Interbedded with the finer varieties of the Jacob deposits there are some more distinctly sandy beds, usually buff or yellowish in color and several feet in thickness, in which particles of fairly fresh granitic minerals can be recognized.

Upward the deposits give place to medium and finally to coarse sands, which in turn give way to the Herod gravels, the intermediate sands being in fact transitional between the two formations.

Details of occurrence.—The best exposures of the Jacob sands are to be seen in the clay pit (figure 6) in the sections at Isabella beach (figures 7 and 8). In the pit, as already stated, there are 40 feet of brownish sandy clay of a chocolate tinge, interlaminated with sands overlying the darker and more plastic Gardiner clay into which they grade. At the first of the Isabella Beach localities the Jacob sands are represented by some 15 feet of fine gray clayey sand intervening between the Gardiner clay and the Herod gravels (figure 7), while at the second some 35 feet are represented with the top unexposed (figure 8). Of this 35 feet the lower 15 are of the usual gray-green clayey sand type, but the upper 22 feet approach a gray sandy clay in character. In an artificial cut near the steamboat wharf on the west side of West harbor a considerable amount of grayish clayey sand of the Jacob type is exposed, as shown in figure 10. The relations in the right-hand half of the figure, especially the upturning and unconformity, are especially characteristic of the conditions at the Jacob horizon in Long island and eastward; but nowhere else save at Sankaty head, Nantucket, has a gravel been seen interbedded with the sands, as shown in the left-hand portion of the figure. There is also somewhat less of the "old look," characteristic of most exposures of the drift of this stage, but this may be due to the freshness of the artificial exposure. The topography, moreover, has a distinctly pre-Wisconsin aspect, and the overlying till resembles the Montauk drift rather than

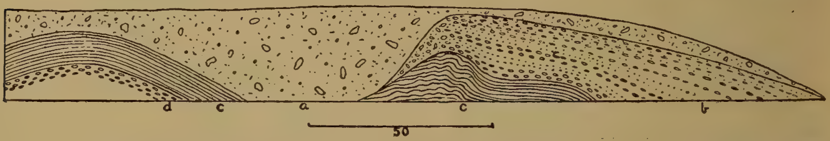

FIGURE 10.—*Artificial Section Exposed in June, 1904, near Steamboat Landing on West Side of West Harbor.*

a, till (Montauk ?); *b*, gravel (Herod ?); *c*, gray clayey sand (Jacob ?); *d*, gravel (probably lens in Jacob sand).

the Wisconsin. For these reasons it seems probable that the clayey sands are to be referred to the Jacob formation.

Along the base of the bluff on the south side of the high hill south of West harbor a thickness of 10 feet of pinkish and brown sandy clay alternating with laminæ of sand is exposed in a low anticline about 100 feet across and a few feet high. This is overlain by gravels of the Herod type and belongs without doubt to the Jacob sands.

Herod gravels—Use of term.—The term "Herod gravels" is applied to the gravels, often from 30 to 50 feet and perhaps in places 100 feet in thickness, which rest conformably upon the Jacob sands and are overlain by the Montauk drift, the contact of which is normally conformable, but which may be replaced by an unconformity due to contemporaneous erosion. It is developed throughout Long island and eastward to Block island, but is generally cut out by the unconformity farther east. The name is from Herod point, near Wading River, on the north shore of Long island, at which locality the gravel is well exposed.

Conditions of deposition.—The conditions as regards submergence which existed during the Jacob deposition continued without very material change through the period of deposition of the Herod gravel. The change from the fine sandy Jacob silts to the latter gravels indicates a near approach of the ice which furnished the materials and the inauguration of swifter currents as indicated by the coarseness of the material deposited. In fact, no clay or fine silts could have been deposited if currents of like strength had existed during the period of Gardiner or Jacob deposition. Whether this was due to currents resulting from the drainage from the ice, from the differences in the depth of water, or from changes in the tidal or other currents resulting from the position of the ice-front can not be established with the information now available. It is believed that the deposition took place under the sea at a distance of only a few miles from the ice-front. The water was deep enough to float bergs, as is indicated by an occasional berg-dropped boulder or by boulder pockets supposed to have been formed through the grounding and melting of bergs. The limited distribution of the boulders of the pockets would seem to show that the bergs were of no great size, indicating that the water was probably shallow at the time. That the ice-margin was close at hand, at least in the later stages, is to be inferred from the fact that the gravels merge upward into semi-till, which could only have been formed in the near vicinity of the ice.

Character of gravels.—The Herod gravels are predominantly sandy, but with a good proportion of pebbles, mainly of granitic rocks. The granites are somewhat weathered, but on the whole do not differ markedly from either the older or younger glacial gravels of the same type.

In fact, the Herod gravel must usually be identified by its stratigraphic position between the Montauk drift and Jacob sands.

Details of occurrence.—The Herod gravels are best exposed in the clay pit, where the sandy phase is strongly developed in the big anticline bringing up the Gardiner clay and Jacob sands. The relations and structure at this point are well shown in figure 6. Figure 11 shows additional details of the structure, although, owing to the talus present, the relations are not entirely revealed.

At Isabella beach the Herod gravels are seen resting on the Jacob sands and with them are arched up in broad open folds (figure 7). The conditions at the West Harbor locality (figure 10), except that the materials are there moderately coarse gravels with pebbles the size of an egg, are similar to those at Isabella beach. The greater part of the high hill on the south shore south of West harbor appears to be composed of Herod gravels, which seem to be cross-bedded on an extensive scale, and which are, judging from the outcrop of the Jacob sands on which they rest, folded into broad arches of a few feet in height.

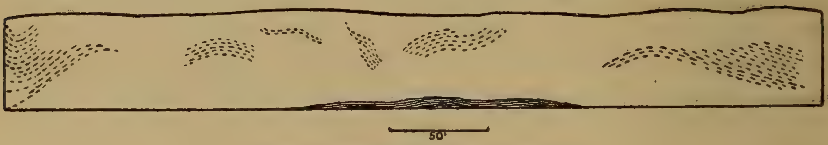

FIGURE 11.—*East-west Section in Clay Pit.*

Showing details of folding in the sandy phase of the Herod gravels; clay at base.

Except at the localities described, where the gravels are seen resting on the Jacob sands, the Herod beds can not be recognized with absolute certainty, although there is every reason to believe that the yellow and buff sands and gravels, which are seen at a great number of points beneath the thin coating of Wisconsin till, belong to this formation, forming, in fact, by far the greater part of the island. They probably reach their greatest development either in the high hills south of West harbor, already mentioned, or in the similar hill southeast of Chocomount cove, which rises to over 120 feet above sealevel and is probably composed mainly of Herod gravels.

Montauk drift—Use of term.—The designation " Montauk drift " is applied to a sheet of drift from 20 to 50 feet or more in thickness, which normally overlies conformably the Herod gravels. Owing to the fact that it was laid down in more or less direct connection with an ice-sheet which alternately eroded and deposited, local unconformities, due to contemporaneous erosion and sometimes cutting as deep as the Gardiner clay, are not uncommon. The material is ordinarily partly stratified, but retains a distinct till-like appearance, owing to the big, probably berg-dropped, boulders present. It takes its name from Montauk point, Long island, where it is typically developed (plate 66, figure 2).

Conditions of deposition.—So far as can be judged from the character of the Herod deposits, the accumulation was entirely submarine. Antedating the beginning of Montauk deposition, however, there was an uplift, bringing the land in the vicinity of Fishers island somewhat nearer to the present level, although, as indicated by the occurrence of the Montauk deposits below sealevel, except when brought up by folding, the level was still lower than that at present existing. The ice-front, which had been remote at the beginning of the deposition of the Jacob sands, had approached nearer during the deposition of the Herod gravels, and at the beginning of the Montauk substage actually invaded the area, passing in its maximum advance over Fishers island and southward to a point beyond Block island. The accumulation seems to have taken place beneath the ice-sheet itself in case of the more till-like deposits, where stratification is absent, while in the case of the semi-stratified materials it probably occurred outside but immediately in front of the margin. The thin beds of true gravels, which are occasionally interbedded with the more till-like deposits, probably represent temporary retreats of the ice-margin to points at some distance from the localities of accumulation.

Character and occurrence of the Montauk drift.—The general features of the Montauk drift have already been outlined and the normal type illustrated in plate 66, figure 2. On Fishers island it is of somewhat different character, although the exposures are typical of certain well defined phases near the type locality. The drift has only been recognized above sealevel at two points: (1) At the West Harbor exposures and (2) in the bluff three-quarters of a mile northeast of the north end of Isabella beach. The " boulders " reported in the Ferguson well probably belong to this formation.

At the West Harbor exposure (figure 10) the Montauk drift is probably represented by the heavy bed of till resting unconformably on the upturned and eroded edges of the Jacob sands and Herod gravels. This unconformity is believed to be the result of essentially contemporaneous erosion by the same ice-sheet that laid down the drift. On Long island, where many more exposures are to be seen, there are similar evidences of slight deposition of till at this time, but the main epoch of folding was of a later date.

At the second of the localities mentioned the exposures show a series of beds of clayey sand alternating with beds of pebbles about the size of a hen's egg occurring in a matrix of clay or clayey sand. Both sand and gravel show the peculiar mixture of coarse grains or pebbles with fine silts, which is characteristic of rapid and only partially assorted deposits such as accumulate at the margin of glaciers. It unquestionably belongs to the Montauk stage, representing certain of the more aqueous phases of deposition. A little farther to the north, although the contact is not seen, the semi-stratified deposits appear to be replaced by till.

Where well exposed, it is usually not difficult to distinguish the Montauk from the Wisconsin drift, the latter, which is relatively sandy and of a buff color, contrasting quite sharply with the older bluish and more clayey drift. In the ordinary imperfect exposures, however, the two can not readily be distinguished, and although certain parts of the till exposed at the surface and at numerous points in the low bluffs of the island may belong to the Montauk, this can not be established with certainty; in fact, it seems probable that most of the surface till is Wisconsin.

Later pre-Wisconsin events.—The accumulation of the Montauk drift on Long island was followed by the deposition of a conformable series of marine gravels, which are found at many points both in the eastern and western parts of the island. In the latter locality they are probably represented by the lower part of the Manhasset gravels of J. B. Woodworth,* or that portion below the boulder bed so well exposed along Hempstead harbor. Following the deposition of these beds the ice, which appears to have temporarily retreated for some distance, readvanced over the whole of eastern Long island and the islands to the east, folding and planing the older beds, but, except in western Long island, where the upper Manhasset was laid down, it deposited very little of the materials now to be seen above sealevel. It is at this time that the severe folding on Fishers island such as shown at the clay pit (figure 6) and at other points (figures 3, 7, and 8) appears to have been produced. It is believed to be contemporaneous with the folding on Block island, at Gay head, etcetera.

During the period commencing with the deposition of the Herod gravel and continuing through the Montauk stage and through the subsequent stage of deposition and folding a gradual subsidence appears to have been going on, until on western Long island, as indicated by the upper level of the marine glacial deposits, the land was 250 feet lower than at present. Fishers island, if not beneath the ice, must have been covered by the sea if a similar depression existed in that region.

Following the retreat of the ice an uplift took place, the land gradually rising from a position 250 feet lower than at present until it stood considerably higher. The uplift was not sudden, there being, on the contrary, several periods of halt, the most marked being at the present

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* Pleistocene geology of portions of Nassau county and the borough of Queens. New York State Mus., Bull. 48, pp. 618-670.

100 and 40 foot levels. At points on the coasts of Long island, Marthas Vineyard, Buzzards bay, and cape Cod there are indications of terraces at both these levels; but if ever present on Fishers island they were so altered by the Wisconsin ice invasion as to be practically unrecognizable. The only suggestion of such a terrace was near the south end of West harbor, where an imperfect 40-foot level was observed.

During this period not only was marine erosion at work, but streams were actively deepening the valleys. On Long island quite a complete drainage system with channels 40 to 80 or more feet deep was developed, being in marked contrast to the post-Wisconsin erosion, which has only cut a few insignificant gullies. In fact, the length of the erosion interval known as the vineyard interval, seems to have been very many, perhaps fifty, times as long as the post-Wisconsin period.

In the central portion of the country the erosion between the Wisconsin and the Iowan stages of glaciation was very slight, indicating a period of rather limited length and one not in harmony with the great length of the Vineyard interval. It seems likely, therefore, that the latter interval covers more than the brief Peorian stage, representing rather the combined Sangamon, Iowan, and Peorian stages. The fact that the Iowan ice did not reach very far south in the Mississippi valley suggests that it may likewise have fallen short of reaching the Long Island region. If the Montauk stage is to be regarded as the equivalent of the Illinoian, there is certainly no evidence of the Iowan on the island.

Wisconsin deposits.—The Wisconsin drift, as already indicated in connection with the descriptions of several of the older deposits, is commonly very thin, being usually represented by a sheet only a few feet in thickness. The ice during its maximum advance completely covered the Fishers Island region, reaching as far as Block island, 10 to 15 miles farther to the south. Allowing a gradient of 40 feet to the mile of the ice surface, which is one frequently assumed, there would have been from 400 to 600 feet of ice over Fishers island. Notwithstanding this considerable thickness, the ice seems to have accomplished very little in the way of erosion. It is doubtless true that there was a further rounding of the pre-Wisconsin hills, although the main sculpturing, if due at all to ice-action, was accomplished by the more powerful Montauk sheet. In fact, beyond a moderate rounding of some of the hills, the scooping out of a few basins in the soft sands, the shoving up of low barriers of drift across old valleys, and the deposition of a thin drift mantle, the Wisconsin ice appears to have accomplished but little. The absence of evidence of pronounced erosion and the slight thickness of the deposits both point to a relatively slow and weak movement of the ice, and it is probable that the period of occupation was not a long one.

The maximum advance occurred in the early part of the stage, the ice reaching as far south as Block island, but later it drew back to Fishers island, or perhaps beyond, where it halted during the building of the morainal deposits. The recession was a relatively rapid one, the inner moraine and its attendant outwash plain being built up, as shown in eastern Long island, before the ice-blocks left by the retreat had time to melt.

The deposits of the Wisconsin stage on Fishers island consist mainly of till, which varies somewhat in character, according to the derivation of the material. When from the island it is buff and sandy, with few boulders, representing, in fact, simply the reworked parts of the underlying materials, especially the Herod gravels. At other points the till is composed largely of granitic materials brought from the mainland. In such till clay is relatively abundant, and, together with the granitic fragments, gives the till its grayish color. Boulders are numerous and often of considerable size.

The best development of till is in the western part of the island, especially west of West harbor. In this region the low bluffs at many points show a till very full of boulders, while the kettle-pitted uplands and the morainic knobs point to more than the ordinary amounts of Wisconsin drift. In the eastern part of the island the Wisconsin drift is thinner, the sands and gravels of the Herod formation being but thinly covered. Sometimes the Wisconsin drift is limited to a few scattered boulders. No stratified materials of this stage are recognized, and, while a few may have been overlooked, it is certain there is no extensive development of such deposits on the island.

Recent history.—There is little record on the island of any post-Wisconsin events. There has been no stream erosion, and the cutting of the bluffs has probably not been extensive. Some small spits have been built, and there has been a slight accumulation of marsh and swamp deposits in spots; but, in the main, there has been little change in the island since the ice left it, other than a possible submergence of a few feet. Even of this, however, no local evidence was found, although from studies on Long island and at points to the east of Fishers island it appears that a subsidence of perhaps 10 feet has occurred since the retreat of the ice.

CORRELATIONS

RELATION OF GARDINER CLAY, JACOB SAND, AND HEROD GRAVEL TO "SANKATY BEDS" (WOODWORTH) OF MARTHAS VINEYARD AND NANTUCKET

The term "Sankaty beds" was proposed by J. B. Woodworth [†]

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[*] The diversity of the glacial period on Long island. Jour. of Geol., vol. xi, 1903, pp. 763-776.

[†] Glacial brick clays of Rhode Island and southeastern Massachusetts. U. S. Geol. Survey, Seventeenth Ann. Rept., pt. i, p. 977.

for a series of marine sands [and gravels] with occasional minor clayey layers, locally carrying a Pleistocene fauna, which are involved in the folding which affected all the New England islands. The name is from Sankaty head, Nantucket, at which point the fossils were first observed. No true clay was exposed at the type locality except a thin fossiliferous bed only a few feet in thickness, although a series of brownish clayey sands incorrectly designated as clay were exposed to a depth of 20 feet at the base of the cliff some 50 years ago.* The remaining portions of the bluff were made up mainly of sands, gravels, and semi-till.

Later Mr A. C. Veatch applied the same name † on the basis of its similar fauna to the blue, gray, or red Pleistocene clays of Long and Gardiner islands, in the former of which they reach, according to the evidence of wells, a maximum thickness of about 100 feet. The writer was originally inclined to the use of this term, ‡ but subsequent field work, during which the shores of the greater part of Long, Gardiner, Plum, Fishers, and Block islands were traversed and the bluff sections of Marthas Vineyard, Nantucket, and cape Cod visited, brought out the fact that the true clays in each of the localities mentioned are stratigraphically below the lowest of the deposits at Sankaty head, and hence should not be included in the term. Moreover, the Sankaty beds of Woodworth are separable into two distinct formations, the Jacob sands and the Herod gravels (see pages 378 and 381), each of which has been traced by the writer from western Long island to Nantucket.

The true clays, to which the term "Gardiner" is given, and the Jacob sands are interglacial deposits, while the Herod gravels are in part, at least, of glacial origin. The term "Sankaty," as used by Woodworth, therefore, includes materials not only of unlike character, but also of diverse origin, while as used by Veatch it includes only a part of the interglacial series. If the term is to be retained, as it possibly will be (because of the well known fauna of Sankaty head), it should, in the writer's opinion, be limited to a single class of deposits, namely, the interglacial deposits here separately described under the headings of Gardiner clay and Jacob sands. The glacially derived Herod gravels should be excluded.

CORRELATION WITH THE DRIFTS OF PENNSYLAANIA, MISSISSIPPI VALLEY, AND CANADA

The geologic successions on Fishers island seem to be essentially similar to those existing on Long island, which may be considered as the type locality of Pleistocene Coastal Plain formations in the northeastern United States. If the interpretations outlined in this paper are correct, four glacial and three interglacial stages have been represented in the upbuilding of both islands.

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* E. Desor and E. C. Cabot: On the Tertiary and more recent deposits in the island of Nantucket. Geol. Soc. Quart. Jour., vol. v, 1849, pp. 340-344.

† The diversity of the glacial period on Long island. Jour. of Geol., vol. xi, 1903, pp. 762-776.

‡ Probable pre-Kansan and Iowan deposits of Long island, New York. Am. Geol., vol. 32, p. 311.

The question of whether the succession of ice invasions in this region was the same as in the central portion of the country and in Canada is difficult to determine. The lobate character of the margins of the earlier ice-sheets in the Mississippi valley is such as to suggest that they might be, to a certain extent, confined to that region. On the other hand, the Wisconsin invasion is known to have reached from the Rocky mountains to the Atlantic coast, reaching nearly as far south in this region as at points farther west.

The most important evidences pointing to the similarity of succession in the Atlantic and Mississippi regions are the relative weathering of the drift, the erosion features of the interglacial stages, and the evidence of elevation or depression of the land in the two regions. For instance, the old extra morainic drift of Pennsylvania (the oldest drift on the mainland east of the Mississippi valley) was deposited when the land was low and the streams relatively sluggish, and on Long island the earliest invasion was associated with a marked depression, the land standing 300 feet below its present level. In each case the period of low level was succeeded by a pronounced uplift, which on Long island resulted in the nearly complete removal of the Mannetto gravels and in Pennsylvania in the very considerable deepening of the Allegheny, Monongahela, and other river valleys. This strongly suggests that the sequence of these early events was not only the same in each case, but that they were contemporaneous.

As to the absolute age of the Mannetto gravel of Long island and the older drift of Pennsylvania, there is little direct evidence except the state of weathering of the pebbles, which is materially greater than in the Kansan deposits of the Mississippi valley; so much so, in fact, that it seems as if an interval of time, perhaps as great as all subsequent Pleistocene time, must have intervened between the deposition of the Mannetto and the Jameco. It is believed that these two drifts, together with the intervening interglacial stage, can be correlated with a fair degree of certainty with the Albertan, Aftonian, and Kansan stages of Canada or the Mississippi valley.

The Jameco gravel is followed conformably by the Gardiner clay and the Jacob sand, both of which are interglacial deposits, and would naturally be referred to the Yarmouth interglacial stage. The Jacob sand is normally followed, in turn, on Fishers island by the Herod gravel and Montauk drift, and on Long island by still other gravels. Between each of these there are local unconformities, such as might be reproduced by readvances of the ice-sheet with which the deposition was associated. Throughout the whole of the series, however, there are no evidences of interglacial soils or of periods of stream erosion ; and while it is certain that the ice invaded the region at least twice, it is believed that the advances simply mark substages of the same invasion, which is regarded as Illinoian.

CORRELATION TABLE

Fishers island.		Mississippi valley or Canada.	
Glacial.	Interglacial.	Glacial.	Interglacial.
Deposition of Wisconsin drift.		Deposition of Wisconsin drift.	
	Erosion.		Peorian soils, etcetera.
	Erosion.	Deposition of Iowan drift.	
	Erosion.		Sangamon soils, etcetera.
Deposition of Montauk drift and Herod gravel.		Deposition of Illinoian drift.	
	Deposition of Jacob sand and Gardiner clay.		Yarmouth soils, etcetera.
Deposition of Jameco gravel.		Deposition of Kansan drift.	
	Erosion.		Aftonian soils, etcetera.
Deposition of Mannetto gravel.		Deposition of Albertan drift.	

Following the deposition of this series of deposits, with its somewhat complicated history, there was a long period of erosion, during which all of the older materials were extensively eroded, both by marine and stream erosion, before the Wisconsin ice invaded the region. From the extent of this erosion it seems probable that the interval was an exceedingly long one, being many times as long as the post-Wisconsin time. This is what would naturally be expected if the period included the Sangamon, Iowan, and Peorian stages of the Mississippi valley, and the correlation with these stages fits in well with the known shortness of the Peorian period in the Mississippi valley, which can not form, judging from the amount of erosion, but a small part of the interval between the Wisconsin and the next preceding invasion in the Fishers Island region.

DISTRIBUTION OF PRE-WISCONSIN FORMATIONS REPRESENTED ON FISHERS ISLAND

MONTAUK DRIFT

Long island.
Gardiner island.
Plum island.
Fishers island.
Block island.
Elizabeth islands.
Nantucket.
Barnstable.
Cape Cod.
Indian hill (Plymouth).
Scituate.
Boston and vicinity.

HEROD GRAVEL

Long island.
Gardiner island.
Plum island.
Fishers island.
Block island.
Marthas Vineyard.
Nantucket.
Truro.
Scituate.
Boston and vicinity.

JACOB SAND

Long island.
Gardiner island.
Plum island.
Fishers island.
Block island.
Marthas Vineyard.
Nantucket.
Cape Cod.
Boston and vicinity (?).

GARDINER CLAY

Long island.
Gardiner island.
Plum island.
Fishers island.
Block island.
Elizabeth islands.
Marthas Vineyard.
Nantucket (below sea).
Truro.
Barnstable.
Indian hill (Plymouth).
Boston harbor (?).

JAMECO

Long island.
Gardiner island.
Fishers island ⎫ (below
Plum island ⎭ sea).
Block island.
Marthas Vineyard.
Barnstable (in well).
Indian hill (Plymouth).
Truro.

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MESOZOIC SECTION ON COOK INLET AND ALASKA PENINSULA*

BY T. W. STANTON AND G. C. MARTIN

(*Presented before the Society December 31, 1904*)

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INTRODUCTION

The localities discussed in this paper are situated in the southwestern part of Alaska, on the shores of Cook inlet and on the Alaska peninsula. Most of them are on the strip of coast forming the southern half of the shore of Cook inlet and the eastern half of the south shore of the Alaska peninsula.

The facts here presented include some of the results of a trip made by the authors in small boats during the summer of 1904 from Snug harbor, on Cook inlet, to Cold bay, on Shelikof strait. Isolated localities both to the eastward and to the westward were also visited.

There are various references to the Mesozoic rocks and fossils of parts of this region. Many of the early references † have been summarized by Dall,[*] who made some valuable original observations on the stratigraphy and paleontology at Tuxedni harbor (Snug harbor), Cold bay, Kialagvik bay, and Wood island, near Kodiak. The fossils collected by Doctor Dall were examined by Professor Alpheus Hyatt, who contributed a brief statement concerning them.[†]

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* Published by permission of the Director of the U. S. Geological Survey.

† C. Grewingk: Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der Nord-West Kuste Amerikas mit den anliegenden Inseln. Verhandl. Russ. Kais. Mineralog. Ges. zu St Petersburg, Jahrg. 1848 und '49 (1850), pp. 121, 344–347.

E. von Eichwald: Geognostisch-Palæontologische Bemerkungen uber die Halbinsel Mangischlak und die Aleutischen Inseln. St. Petersburg (1871), pp. 88–200.

J. Marcou: Explication d'une seconde edition de la carte geologique de la terre. Zurich (1875), pp. 138–140.

Professor J. F. Pompeckj[‡] has examined and described some of the Jurassic collections obtained by the Russians more than half a century ago and has briefly discussed the age and correlation of the beds. Dr E. O. Ulrich[§] has described the fossils of the Yakutat series, which he referred to the Lias. This formation occurs on Kodiak and adjacent islands and on Yakutat bay, but has not been seen on the mainland of the Alaska peninsula. Mr J. E. Spurr crossed the Alaska peninsula at Naknek lake and Katmai in 1898, and has described[‖] the Mesozoic section exposed in that region.

The junior author visited a few localities on these shores in the summer of 1903, and has described[¶] part of the Mesozoic stratigraphy, but no connected account of the entire Mesozoic section giving any adequate idea of the thickness and stratigraphic relations of the different formations has been previously published.

General Geology of the Region

The most prominent topographic features of this region are three distinct mountain ranges, with two intervening valley regions. These extend roughly parallel in an approximately northeast-southwest direction. The Chigmit mountains are at the northwest and extend from mount Redoubt, near the northern end of Cook inlet, to the southeast corner of Iliamna lake. The Aleutian mountains occupy the axis of the Aleutian

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Paul Fischer: Sur quelques fossiles de l'Alaska, in voy. a la côte N. W. de l'Am. 1870–'72, par Alphonse Pinart. Paris, 1875, pp. 33–36, pl. A.

Charles A. White: On a small collection of Mesozoic fossils obtained in Alaska by Mr W. H. Dall. Bull. U. S. Geol. Survey, no. 4, 1884, pp. 10–16, pl. vi.

M. Neumayr: Die geographische Verbreitung der Jura-formation. Denkschr. der Wiener Akademie, Bd. 50 (1885), pp. 93, 94.

C. A. White: Mesozoic mollusca of the southern coast of the Alaskan peninsula. Bull. U. S. Geol. Survey, no. 51 (1889), pp. 64–70.

[*] Report on the coal and lignite of Alaska. Seventeenth Ann. Rept. U. S. Geol. Survey, pt. i, pp. 865–869.

[†] Report on the Mesozoic fossils: Report on the coal and lignite of Alaska. Appendix iii, Seventeenth Ann. Rept. U. S. Geol. Survey, pp. 907–908.

[‡] Jura-Fossilien aus Alaska. Verhandl. Kais. Russ. Min. Gesellschaft., 2d ser., vol. xxxviii, pp. 239–282, pls. v–vii. St. Petersburg, 1900.

[§] Harriman Alaskan Expedition, vol. iv, Geology, pp. 125–146.

[‖] Reconnaissance in southwest Alaska. Twentieth Ann. Rept. U. S. Geol. Survey, pt. vii.

[¶] Petroleum fields of Alaska and the Bering River coal fields. Bull. 225, U. S. Geol. Survey, pp. 376–381.

The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits. Bull. 250, U. S. Geol. Survey.

islands and the Alaska peninsula, having their eastern termination on cape Douglas, at the mouth of Cook inlet. The Kenai mountains occupy the southeastern half of the peninsula of that name, and have their western termination at cape Elizabeth, with a possible detached extension in the lower summits of Afognak and Kodiak islands.

The Alaska peninsula contains a coarse crystalline core of granite or of similar rocks, flanked on the eastern side by Mesozoic sediments and on the western side by late Tertiary or post-Tertiary beds. The Mesozoic beds are overlain in places by early Tertiary formations. Both the Mesozoic and the Tertiary beds are cut by andesite and basalt. The intrusion and volcanic outflow has continued from late Jurassic time until the present, the region containing several active volcanoes.

The structure of the region is varied. The west shore of Cook inlet has its general position outlined by a number of great overthrusts, by which the Triassic rocks have been brought in contact with the Upper Jurassic. The Alaska peninsula is a region of open folding, with the folds cross-cut by an irregular series of faults.

The general distribution of the Mesozoic rocks throughout the region discussed is shown in the sketch map, figure 1, and a somewhat more detailed map of part of the coast of Cook inlet is given in figure 2.

Mesozoic Formations and Faunas

UPPER TRIASSIC

Upper Triassic rocks have been seen on the north shore of Bear cove and on Bear bay, both on the west shore of Cook inlet, and on the Alaska peninsula at the entrance to Cold bay and extending several miles eastward. They are also probably present at numerous localities on the south shore of Kachemak bay, as at Halibut cove and Seldovia, where there is a great development of thin bedded and contorted cherts, with some silicious limestone and igneous rocks. This series is tentatively correlated with the fossiliferous Trias on the west shore of Cook inlet on account of lithologic and structural resemblances and because of its association with the Lower Jurassic.

The Triassic rocks of Cold bay, Bear cove, and Bear bay, whose age has been definitely determined by fossils, consist of thin bedded chert, limestone, and shale of varied colors. The chert and limestone are usually dark-black, green, or dark-red when fresh, but weather to lighter shades. No measurement of the thickness has been made, but it is estimated to be at least 2,000 feet in the exposures seen by us, in which the base was always cut off by intruded igneous rocks.

These rocks are always closely folded and are frequently crumpled. They are usually cut by numerous dikes of diverse character and composition, varying from granite to andesite and basalt. The more acid dikes are apparently characteristic of the Triassic rocks, and were intruded soon after the folding which must have closely followed Triassic time, for they do not cut the younger rocks. A characteristic exposure of these folded beds is shown in plate 67, figure 1, and their relation to the Jurassic is indicated by the comparatively undisturbed condition of the Upper Jurassic sandstones less than one-fourth mile distant, as seen in plate 68, figure 2.

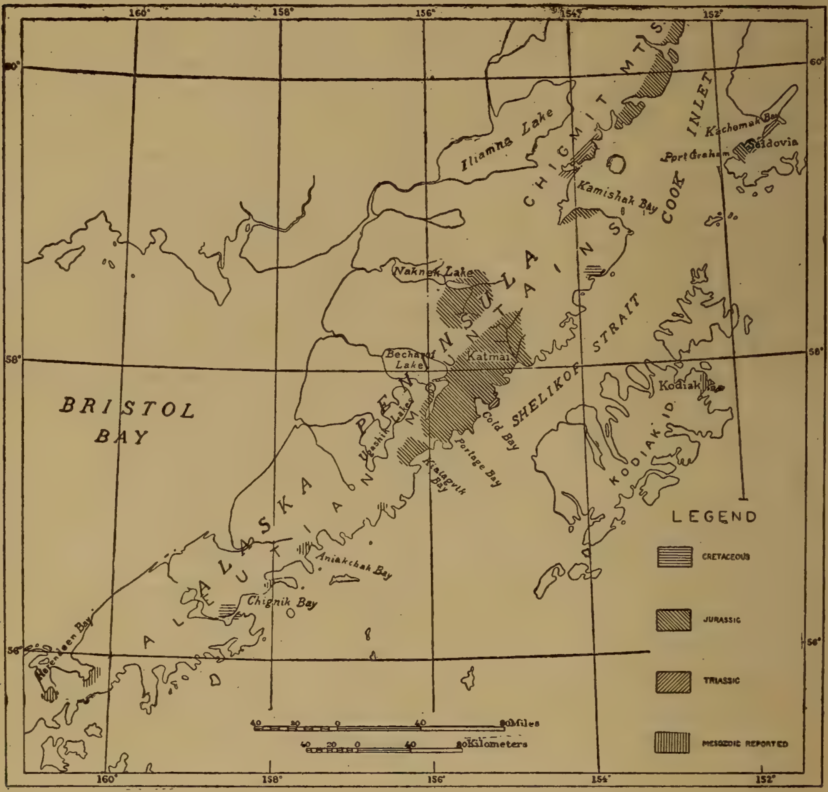
160°
158°
156°
154°
152°
60°
58°
56°
Iliamna Lake
CHIGMIT MTS
COOK INLET
Kachemak Bay
Port Graham
Seldovia
Kamishak Bay
Naknek Lake
Becharof Lake
Katmai
ALASKA PENINSULA
ALEUTIAN MTS
SHELIKOF STRAIT
Kodiak
KODIAK ID
BRISTOL BAY
Ugashik Lakes
Cold Bay
Portage Bay
Kialagvik Bay
Aniakchak Bay
Chignik Bay
Herendeen Bay
40 20 0 40 80 Miles
40 20 0 40 80 Kilometers
LEGEND
CRETACEOUS
JURASSIC
TRIASSIC
MESOZOIC REPORTED

FIGURE 1.—*Map of Cook Inlet and the Alaska Peninsula.*

Showing the distribution of the Mesozoic rocks.

The Triassic fauna of the region as now known is almost limited to the single species *Pseudomonotis subcircularis* Gabb, which is very abundant in certain layers of shale and limestone at Bear cove and Cold bay. Specimens from the latter locality were described and figured by Fischer as *Monotis salinaria*, which it resembles in its general features, but a comparison of a large series of specimens from Alaska with a similar series

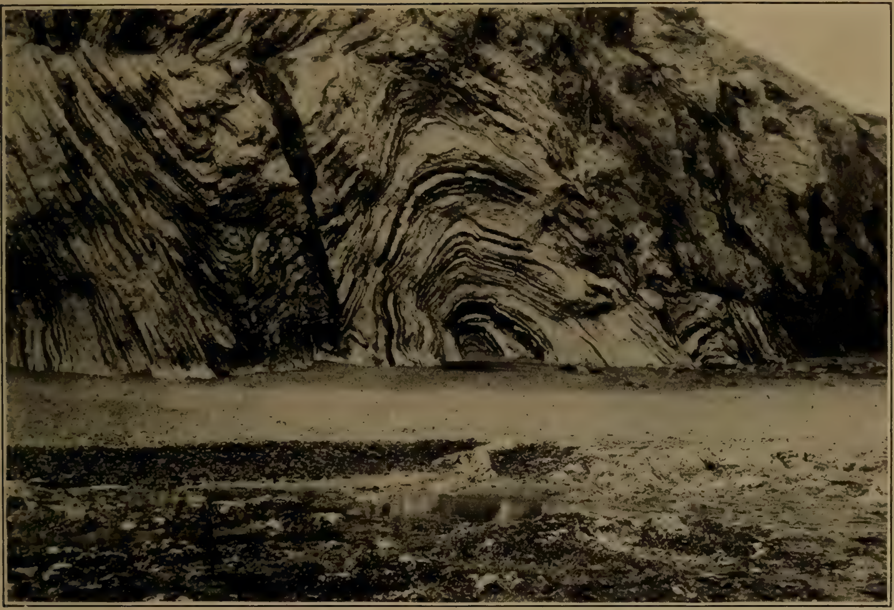

Figure 1.—Folded and faulted Triassic Limestone and Cherts, Bear Bay, Cook Inlet

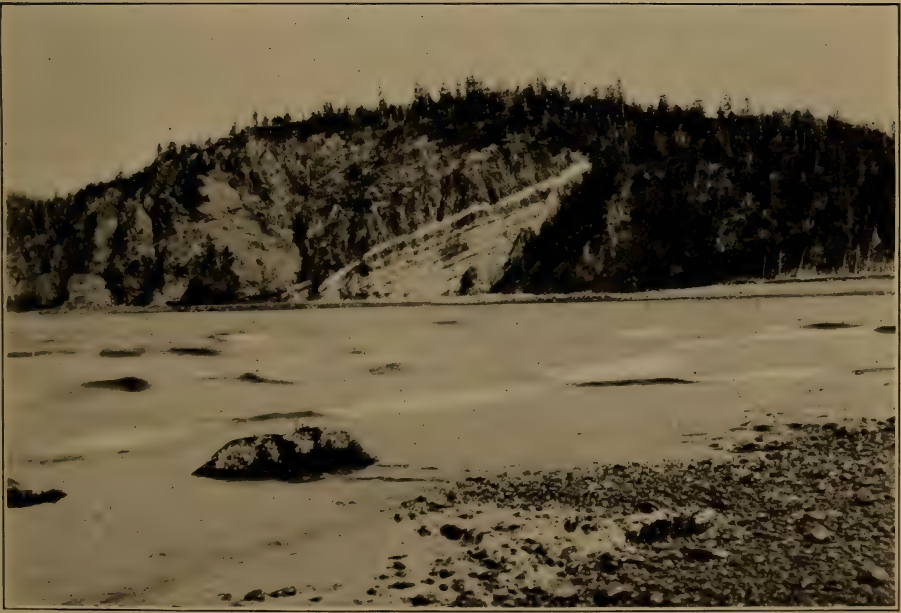

Figure 2.—Lower Jurassic Tuffs and cherty Limestone, Port Graham

TRIASSIC AND LOWER JURASSIC FORMATIONS IN ALASKA

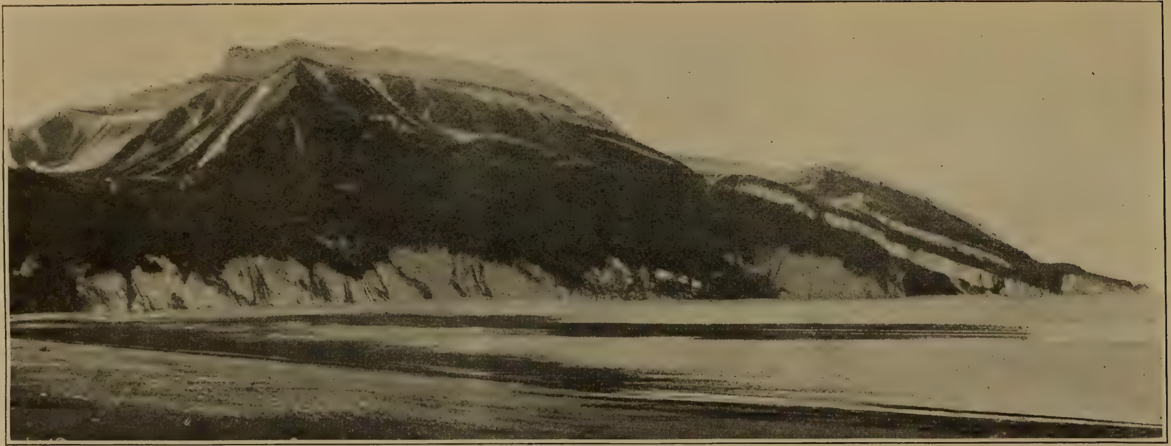

Figure 1.—Enochkin and Naknek Formations on east Side of Oil Bay, Cook Inlet

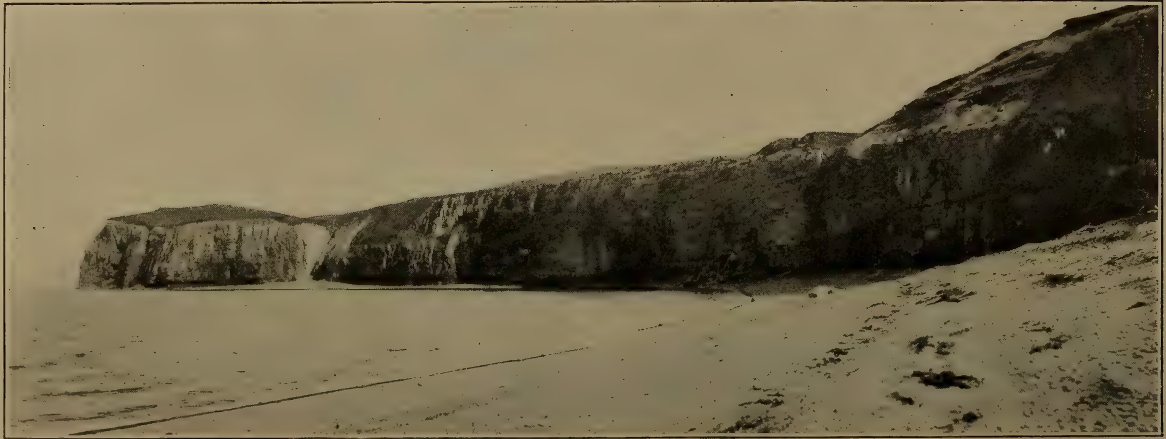

Figure 2.—Naknek Sandstones, Bear Bay, Cook Inlet

ENOCHKIN AND NAKNEK FORMATIONS, ALASKA

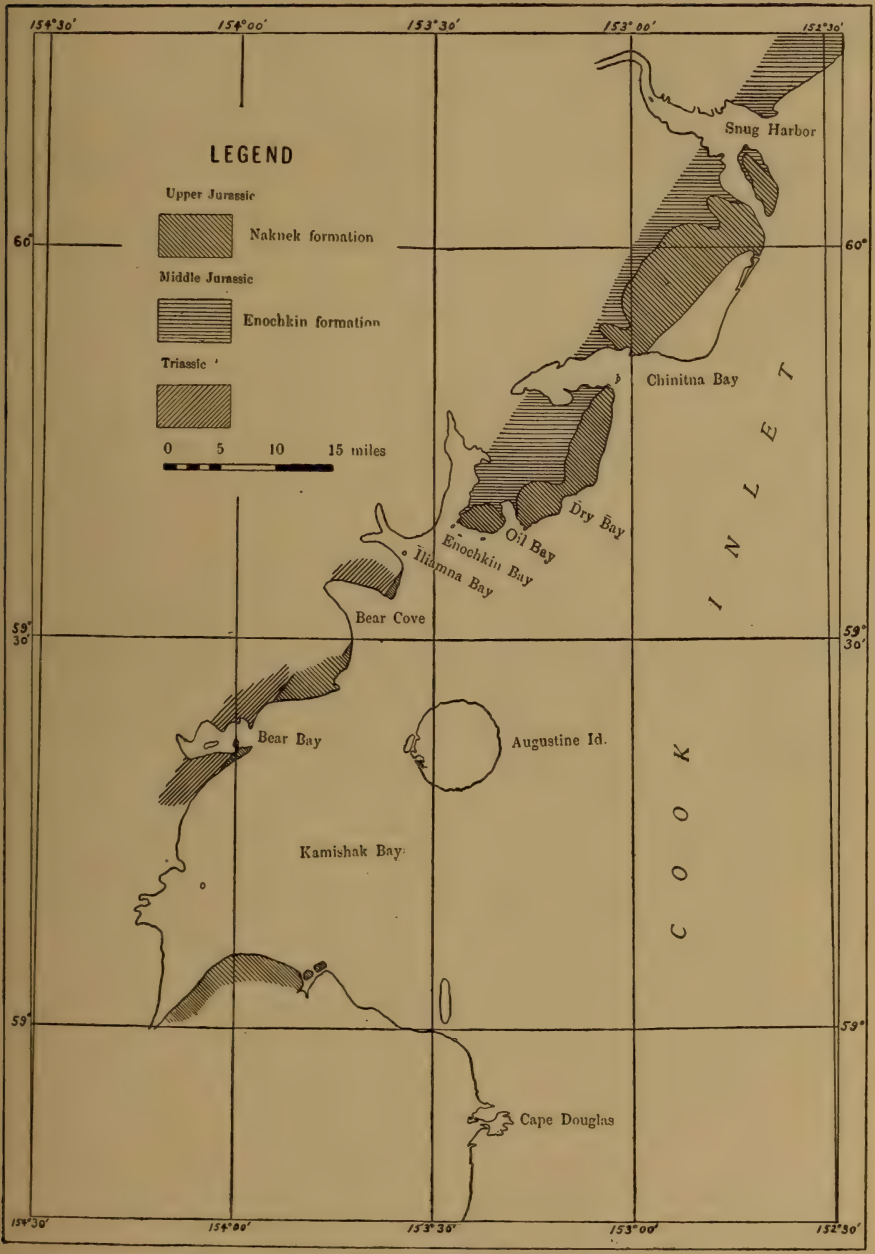
154°30'
154°00'
153°30'
153°00'
152°30'
60°
59° 30'
59°
LEGEND
Upper Jurassic
Naknek formation
Middle Jurassic
Enochkin formation
Triassic
0 5 10 15 miles
Snug Harbor
Chinitna Bay
Dry Bay
Oil Bay
Enochkin Bay
Iliamna Bay
Bear Cove
Bear Bay
Augustine Id.
Kamishak Bay
Cape Douglas
COOK INLET

FIGURE 2.—*Map of Part of the West Coast of Cook Inlet.*

Showing the distribution of the Mesozoic formations.

of Gabb's California species shows that they are not separable. The species belongs to the group of *Pseudomonotis ochotica*, which is characteristic of the Upper Triassic of Siberia and the boreal regions generally.

In California *Pseudomonotis subcircularis* is confined to the Swearinger slates, which form the uppermost Triassic formation of that region. Similar beds with the same fossil occur in Vancouver and Queen Charlotte islands and on the mainland of British Columbia, and they cover considerable areas in the Copper River region of Alaska.

At Bear bay the much folded Triassic limestone yielded imperfect specimens of a Halobia, and at Cold bay a few imperfect Ammonites not generically determined were obtained in beds overlying the Pseudomonotis layers, but possibly still within the Triassic.

One other area of probable Triassic has been reported by Hyatt* from cape Thompson, northwest Alaska, on account of the supposed occurrence of Halobia or Daonella there, but subsequent collections from that region have proved the rocks to be Paleozoic.

LOWER JURASSIC

In the neighborhood of Seldovia there is a considerable thickness of sedimentary and associated igneous rocks that are believed to be Lower Jurassic. They lie west of the cherts previously mentioned as of probable Triassic age, and are not so much disturbed and metamorphosed as the cherts, from which they are doubtless separated by an unconformity, though the dips, which vary in both direction and amount, average perhaps 40 or 50 degrees and in some exposures are as much as 70 degrees. The rocks are apparently composed almost exclusively of fragmental igneous material, and should be classified as tuffs rather than sandstones and conglomerates. The fine grained beds are dark greenish gray when fresh, but weather to lighter shades, while some of the coarser beds, made up of more or less angular fragments, are red, greenish, and variegated.

This series was seen on the west shore of Seldovia bay at the entrance to the harbor and for 3 miles westward along the shore of Cook inlet; also on the east shore of port Graham south of the coal-bearing Kenai exposures. At the latter locality the section includes a conspicuous bed of light colored cherty limestone (see plate 67, figure 2). It is probable that the "dense Neocomian limestone" near English bay, from which Eichwald cited *Arcomya crassissima* and a Janira, belongs in this series.

Fossils are not very abundant nor well preserved, but those obtained on Seldovia bay and along the coast for 2 miles to the westward indicate a horizon low in the Jurassic. They include Pentacrinus, a Trigonia of the section Glabræ, Cardinia (?), Myophoria (?), Gryphæa, three or more species of Pecten, Pinna, and two or three species of Ammonites represented by fragmentary specimens, one of which seems to be an Arietites or a closely related form. The Myophoria (?) is a small shell with four strong radiating ribs, and if the genus is correctly determined it would suggest an age as old as the Rhetic, but the other fossils give stronger evidence of Jurassic age. None of the fossils in this little assemblage is known elsewhere in Alaska, and we are unable to make any definite correlation with other American formations, although rocks of the same age doubtless occur in the California section.

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*Seventeenth Ann. Rept. U. S. Geol. Survey, p. 907.

It is probable that Lower Jurassic rocks of a different character occur on the Alaska peninsula. At Cold bay there are nearly 4,000 feet of shales and sandstones lying between the determined Triassic rocks and the Cadoceras-bearing Enochkin formation, but their exact position in the Jurassic or Triassic was not determined by paleontologic evidence. In the Cold Bay section the unconformity between the Triassic and the Jurassic is not so obvious as at some other localities, and the boundary between the two systems was not definitely fixed by our very limited examination, the relations being obscured by several important faults and by the absence of characteristic fossils in the critical part of the section. It is more than probable, however, that there is an unconformity above the Triassic. The Ammonites from Kialagvik or Wide bay described by White are referred by Pompeckj to the Upper Lias, and Hyatt referred other collections from the same bay to the base of the Lower Oolite, stating that they are related to faunas that are called Upper Lias by German geologists. These are in unaltered sandstones, and whatever may be the final decision as to their age, they are evidently older than any part of the Enochkin formation. Hyatt also tentatively referred certain specimens of Lytoceras and Phylloceras from Kamishak bay to the Upper Lias, but we now know that they really come from the Upper Jurassic Aucella beds of the Naknek formation.

The Yakutat formation, on Kodiak island, across Shelikof strait from the Alaska peninsula, which was referred to the Lower Jurassic by Ulrich, differs completely in both lithologic and paleontologic features from all the Jurassic formations known in the region, and as the fossils it has yielded are all new forms of doubtful affinities, its exact age is still uncertain.

MIDDLE JURASSIC—ENOCHKIN FORMATION

The Enochkin formation is typically exposed on the east shore of Enochkin bay, from which it was named.* It extends from here in a continuous belt west of and parallel to the shore of Cook inlet at least as far northward as Snug harbor. It also covers a large area on the Alaska peninsula in the vicinity of Cold bay. The occurrence of *Cadoceras wossnessenskii* reported "near Katmai" by Grewingk indicates another possible locality for the rocks of this formation in the Cold Bay area.

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* The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits. Bull. 250, U. S. Geol. Survey, 1904, pp. 37-55.

The following section shows the character of the formation at the type locality, essentially as described in the paper just cited:

Compiled detailed section of the Enochkin formation

	Feet
Zone D:	
Drab shale with numerous bands of limestone concretions filled with well preserved specimens of various ammonoids, mostly Cadoceras and Belemnites, with occasional sticks of fossilized wood	146
Concealed by talus (all shale as above), thickness computed	77
Shales as above with same concretions and wood	196
Limestone	1
Shales as above	363
Shales (partly concealed by talus), thickness computed	300
Shales as above with *Cadoceras doroschini* and a few other fossils	200
Concealed	25
Zone C:	
Sandy shales with many Belemnites and other fossils	50
Concealed	20
Soft shale	20
Dark drab shale with scattered fossils	33
Hard calcareous shale full of fossils, principally Inoceramus, Pleuromya, and other pelecypods	2
Black sand	1
Dark shale	5
Black sand	..
Dark shale with many fossils	12
Reddish limestone	½
Dark shale with many fossils	14
Dark shale with scattered fossils	62
Dark soft sandstone with streaks of conglomerate	10
Concealed	..
Zone B:	
Shale with several fossil bands containing *Trigonia doroschini*, etcetera	50
Concealed	..
Zone A:	
Shale with one or more bands packed with fossils—*Trigonia doroschini*, *T. devexa*, etcetera—each fossil bed 10 to 25 inches thick	30
Concealed	..
Shale	12
Coarse conglomerate	20
Unconformity	..
Greenish basalt	..
Total	1,650

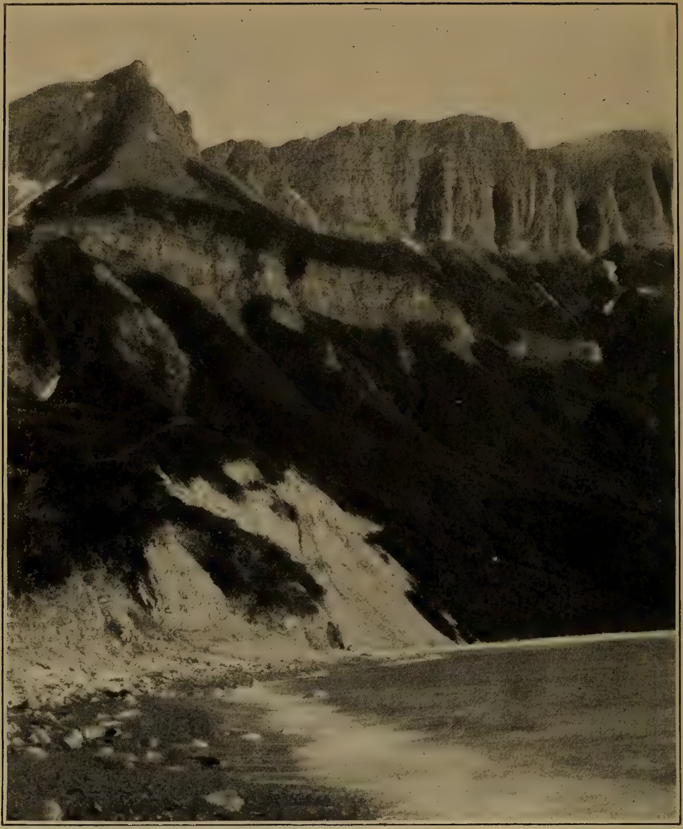

Figure 1.—Enochkin and Naknek Formations, Enochkin Bay, Cook Inlet

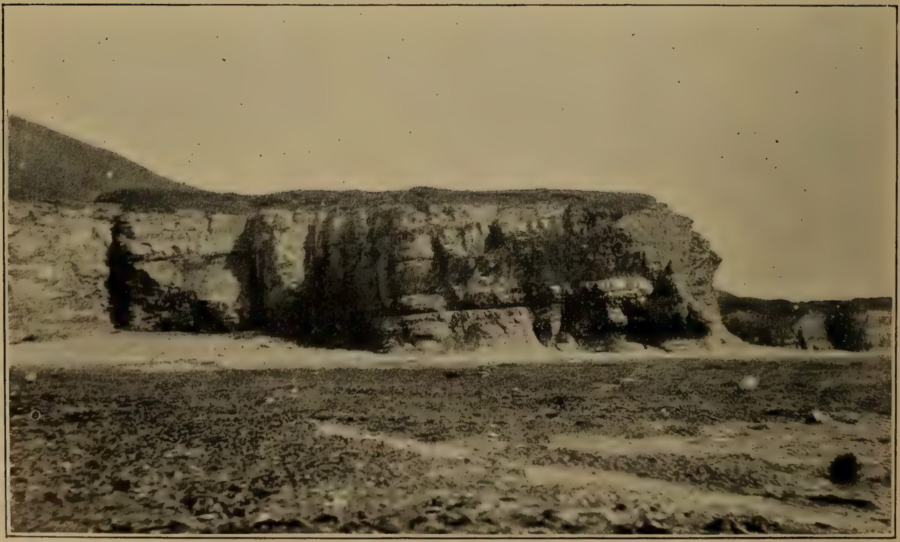

Figure 2.—Naknek Sandstones, Rocky Bay, Cook Inlet

ENOCHKIN AND NAKNEK FORMATIONS, ALASKA

The concealed intervals in the lower part of this section are very large, only about half of the total thickness being shown. Both top and base are, however, represented. The accompanying photograph (plate 69, figure 1) shows the exposure of zone D and the overlying Naknek formation in this section. The following sections fill most of the gaps:

Section of part of Enochkin formation on south shore of the west arm of Snug harbor

	Feet
Shaly sandstone with scattered fossils, Inoceramus, Trigonia, Sphæroceras, Phylloceras, etcetera	55
Black sandstone with small white angular grains	8
Hard gray sandstone	1
Black sandstone with *Inoceramus ambiguus*, *Stephanoceras* cf. *humphriesianum*, *Sphæroceras oblatum?* etcetera	3
Dark shale	8
Soft coarse black sandstone with white grains	39
Fine grained gray shale with *Sphæroceras oblatum*, Belemnites, etcetera	18
Fine grained gray shale	35
Bands of sandstone and shale	4
Dark soft shaly rock with coarse grains	10
Dark limestone with abundant fossils, *Sphæroceras cepoides*, Pleuromya, etcetera	3
Dark shale	3
Dark conglomerate rock (arkose)	7½
Dark shale with conglomerate bands	26
Sandstone	1
Gray shale	15
Sandstone	2½
Shale with scattered fossils	12½
Sandstone and shale, *Stephanoceras carlottense*, *S. richardsoni*, *Sphæroceras cepoides*, Lytoceras, Phylloceras, and many other fossils	3
Shale with concretionary bands	10
Concealed by a fault	±100
Gray shale with numerous sandstone and concretionary bands and occasional fossils, including *Stephanoceras* cf. *humphriesianum*	100
Gray shale with occasional sandstone and concretionary bands	150
Gray sandstone with *Inoceramus ambiguus* and a few other bivalves	120
Limestone conglomerate with clavellate and undulate Trigonias, etcetera	1½
Gray sandstone	3
Dark gray fossiliferous sandstone	1
Gray sandstone with many small fossils	11
Fossiliferous conglomerate with Belemnites	2
Shaly sandstone with *Inoceramus lucifer* and *Lima* cf. *gigantea*	52
Sandy shale with a few thin indurated fossiliferous sandstone bands	35
Indurated ledges of argillaceous sandstone 1 to 4 feet thick, alternating with somewhat thicker beds of clay (fossiliferous)	25
Shale with abundant Ammonites, Stephanoceras, Harpoceras, etcetera	20

	Feet
Indurated bands of sandstone in ledges 1 to 1½ feet thick, alternating with thicker beds of shale	14
More or less sandy shale weathering yellowish	100
Sandstone with clay partings with abundant *Lima* cf. *gigantea*	36
Softer sandstone and shale to base of exposure, partly covered by shale talus	100
Total	1,128

This section on the mainland at Snug harbor all lies beneath the horizon of zone D in the Enochkin section—that is, it does not contain any beds with Cadoceras, but on Chisik island, less than 2 miles to the eastward, the upper members of this section, or other beds with the same fauna, are overlain by shales and sandstones with the Cadoceras fauna, and these in turn are followed conformably by the shales, sandstones, and agglomerates of the Naknek formation with Aucella, etcetera.

Section of Enochkin formation at Oil bay

	Feet
Dark shale with concretions	690
Hard dark sandstone	½–¾
Dark drab shale with numerous concretions	530
Calcareous shale with *Cadoceras schmidti* Pompeckj *Cadoceras* sp. cf. *C. stenoloboide* Pompeckj, and Phylloceras	1
Dark shale with *Cadoceras doroschini*, etcetera	60
Soft green sandstone	½
Dark-drab shale	12
Total	1,293

At Oil bay, which is only 3 or 4 miles from Enochkin bay, the base of the exposure is in the dark shales of zone D with *Cadoceras doroschini* and a few other forms. The Enochkin formation is here overlain by a good development of the Naknek formation, described on a succeeding page, and the character of the exposures is shown in the photograph (plate 68, figure 1).

Section of Enochkin formation on north shore of Chinitna bay

	Feet
Indurated dark argillaceous shales with conspicuous thin bands and elongated lenses of yellowish impure limestone	500

At this point a change in the strike of the beds and in the direction of the coast carries the cliffs some distance from the shore. The section is continued on a small creek which enters the bay about half a mile west of the sea cliffs. Along this creek the exposures are not so continuous nor so conspicuous as those in the sea cliffs, but they are sufficient to show the relation of the beds to the general section.

Dark shales with occasional more indurated bands of argillaceous sandstone	425
Dark shales with beds of argillaceous sandstone forming many cascades, Cadoceras found near the middle	650

	Feet
Indurated bands of argillaceous sandstone with abundant specimens of Cadoceras and Belemnites	10
Dark shales and argillaceous sandstones	115
Similar beds not well exposed	200
Dark shales weathering to brownish slopes with bands of small concretions containing *Cadoceras doroschini*, etcetera	330
Similar shales mostly covered.	75
Dark clay shales weathering brownish with concretions containing Cadoceras, etcetera, near middle	110
Total	2,415

This section, like that at Oil bay, contains no beds lower than zone D, and it is overlain by an immense thickness of the Naknek formation. No fossils were found in the upper 1,000 feet or more which are assigned to the Enochkin formation on lithologic grounds.

The Enochkin formation, as defined and described in the preceding pages, might well be divided into two formations, differing somewhat lithologically, and each characterized by a distinct fauna. In the upper two-thirds shales predominate, and the most characteristic fossils are several species of Cadoceras. This portion, which we have mentioned as "zone D" or the "Cadoceras zone," has been recognized by its fossils from Snug harbor to Cold bay. Its characteristic Ammonites have been assigned to the Callovian by Neumayr, Hyatt, and Pompeckj, all of whom recognized the character of the fauna, which is represented by closely similar forms in Russia, Franz Josef Land, and elsewhere in northern regions, as well as in other parts of Europe. This Callovian fauna is placed by many geologists in the lower part of the Upper Jurassic, but it seems to accord better with the local development in Alaska to follow the custom of some German geologists and assign it to the top of the Middle Jurassic. Seven species of Cadoceras have been named from Alaska, some of which will evidently become synonyms when the large collections now on hand are fully studied, and possibly one or two additional names will be necessary. With these are associated Sphæroceras, Phylloceras, and one or two other genera of Ammonites, Belemnites, and a very few pelecypods and gastropods. A few plants, referred by Dr F. H. Knowlton to *Cladophlebis denticulata*, *Ctenis grandifolia*, *Hausmannia* sp., and *Dictyophyllum* cf. *D. obtusilobum*, have been found with the marine invertebrates. In addition to the localities on Cook inlet and the Alaska peninsula, Pompeckj has described several species of Cadoceras in an early Russian collection, said to have come from the "Sotkin'sches Ufer" of Kodiak island, but it is possible that the locality given is erroneous.

The lower third of the Enochkin formation contains a larger proportion of sandstones, and the fauna, except possibly a few species of Belemnites and pelecypods, is entirely distinct. This part of the formation was studied by us at only two localities, namely, Snug harbor and Enochkin bay. At Snug harbor the section exposed is much thicker and more fossiliferous, being especially rich in Ammonites, which are very scarce at Enochkin bay, but the two localities have enough common species to make the correlation of the beds positive. Many of the Alaskan fossils described by Eichwald came from Snug harbor and a large proportion of the species referred by him to the Neocomian and the Gault came from this horizon. It was interesting also to find here several species originally described by Whiteaves from Queen Charlotte islands and supposed to have come from Cretaceous rocks. Among them are *Stephanoceras loganianum*, *S. Carlottense*, *Sphæroceras oblatum*, *S. cepoides*, and possibly *Trigonia dawsoni*, which are associated with *Stephanoceras* cf. *humphriesianum*, several other species of Stephanoceras, Phylloceras, Lytoceras, *Lima* cf. *gigantea*, and many other forms in beds several thousand feet below the top of the Jurassic. The most common fossils in this zone are the several forms of Inoceramus described by Eichwald as *I. ambiguus*, *I. porrectus*, *I. eximius*, and *I. lucifer*, by means of which the horizon has been recognized by collections obtained by Brooks and Prindle in the Alaskan range near the headwaters of the Kuskokwim, and its presence is suggested in the Kennicott formation of the Copper River region by doubtful specimens in the collections of Schrader and Spencer.

A few fossil plants associated with the Ammonites have been identified by Doctor Knowlton as *Sagenopteris göppertiana*, *Pterophyllum rajmahalense*, and *Macrotæniopteris californica*.

Hyatt examined a few fossils from Snug harbor and referred them to the inferior Oolite or Middle Jurassic. No closely similar fauna has been found elsewhere in Alaska or on the American continent, except on the Queen Charlotte islands, where certain localities in the "Lower Shales" have yielded Ammonites and a few other forms that evidently belong to this fauna and have no connection with the Cretaceous fauna from other localities on Queen Charlotte islands, supposed to be in the same formation. Its exact correlation with European Jurassic faunas must await the exhaustive study and description of the collections, but it certainly includes at least a part of the Lower Oolite or Middle Jurassic.

UPPER JURASSIC—NAKNEK FORMATION

The Naknek formation was described by Spurr* from the vicinity of Naknek lake and Katmai, on the Alaska peninsula. He says of it:

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*A reconnaissance of southwestern Alaska. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 169–171.

> "The Naknek series consists of a great thickness of granitic arkose and of conglomerate which generally contain pebbles of granite. All of these sedimentary rocks are evidently derived from the destruction of a land mass which consisted largely of hornblende-biotite-granite. There are probably some volcanic flows interstratified with the arkose and conglomerates, although it is not absolutely proved that those examined may not be intrusive. The series is cut by andesite-basaltic (aleutitic) lava of later age, especially along the axis of the range, where the amount of volcanic rock is very great.
>
> "Throughout the whole series the arkoses carry abundant fossil remains, both of plants and of marine organisms."

Elsewhere he alludes to the presence of beds of gray compact limestone in the formation, and on page 180 he adds:

> "Throughout the whole series are abundant plant remains, which, so far as examined, were not determinate, and marine faunal remains that indicate a probable Upper Jurassic age."

He estimates the thickness exposed in the mountains near Katmai as at least 1,500 feet. The section in the cliffs on the east side of Katmai bay is described as consisting of hard and massive dark-gray granite arkose at the bottom, overlain by a probable flow of massive andesite, above which are arkose and conglomerates. Gray compact limestone with Jurassic fossils is found at various points in the rocks.

The Naknek formation occupies a large area on the Alaska peninsula, in the vicinity of Katmai and Naknek lake, extending southward beyond Cold bay and Becharof lake. It also extends along the shore of Cook inlet from Snug harbor to the mouth of Enochkin bay and occurs on the shore of Kamishak bay between Bear cove and Bear bay, south of Bear bay and west of Douglas river. Wherever its base is seen it rests conformably on the Enochkin formation.

The following sections show the development of the formation in exposures on the west shore of Cook inlet:

Section of Naknek formation on the north shore of Chinitna bay

	Feet
Tertiary shales, sandstones, and conglomerates with a few Kenai plants....	..
Coarse conglomerate with 6-inch (maximum) granite pebbles and smaller pebbles of various lithologic character in a tuffaceous or arkose matrix...	10
Shaly arkose or sandstone	2½
Conglomerate	2½
Arkosic sandstone or andesite	1½
Conglomerate	1
Massive tuffaceous rock with numerous inclusions	9
Tuffaceous rock with much shale	3
Andesite	12
Shale	2
Concealed	10

	Feet
Andesite	15
Concealed	5
Contorted shale with large Belemnites at base	23½
Sandstone	½
Shale	½
Andesite	4
Contorted shale with concretions	3
Andesite or arkose with granite pebbles at top	7
Sandy shale	2
Sandy shale with fossil band at top (Aucella bed)	3
Dark shale	15
Conglomerate with shaly matrix	5
Sandstone	½
Conglomerate	3
Dark shale	4
Conglomerate with dark matrix	13
Agglomerate	9
Dark shale	20
Coarse conglomerate	2½
Pinkish sandstone with pebbly bands	2
Conglomerate	5¾
Sandstone	½
Shales	½
Andesite	2
Agglomerate	2
Andesite	7
Sandstone with shale bands	8
Dark shale	25
Concealed (for 1,350 feet at 20 degrees dip)	462
Andesite	18
Concealed (for 100 feet at 20 degrees dip)	34
Andesite	10
Concealed (for 50 feet at 20 degrees dip)	17
Andesite	5
Concealed (for 130 feet at 20 degrees dip)	44
Andesite	32
Agglomerate	3
Arkose with shaly bands	19
Andesite with agglomerate at base	55
Andesite	30
Shale	6
Andesite	79
Concealed (for 430 feet at 25 degrees dip)	182
Agglomerate	60
Agglomerate	3
Andesite	185
Shale	1
Andesite	158
Agglomerate	2

	Feet
Andesite tuff with abundant pebbles	60
Shale	4
Concealed (for 60 feet at 24 degrees dip)	24
Sandy shale	68
Sandstone and shale	30
Andesite	25
Concealed (across cove for 800 feet at 25 degrees dip)	338
Coarse gray sandstone, mostly heavy bedded	66
Alternating bands of sandstone and shale	7
Coarse gray sandstone	12
Concealed	10
Coarse gray sandstone	25
Shaly sandstone	4
Coarse gray sandstone	26
Coarse gray sandstone with bands of fine conglomerate	5
Coarse gray sandstone with thinner shaly bands	27
Coarse gray sandstone with bands of fine conglomerate	162
Fault? Displacement probably small.	
Coarse gray sandstone with bands of fine conglomerate	50
Dark shaly sandstone	25
Alternating bands of shaly sandstone and fine conglomerate	10
Coarse gray sandstone with bands of fine conglomerate	12
Dark shale	2
Coarse gray sandstone and fine conglomerate	21
Dark shale with Belemnites	40
Coarse gray sandstone	25
Dark shale with thinner bands of coarse gray sandstone	100
Massive coarse gray sandstone	60
Coarse gray sandstone with more shaly layers	125
Covered except two or three small outcrops of shaly sandstone	425
Dark shales with Belemnites	160
Cross-bedded coarse sandstone	30
Dark shales and shaly sandstone with Aucella, etcetera	290
Alternating bands of coarse gray and argillaceous fossiliferous sandstone	100
Coarse gray sandstone	20
Thin bedded argillaceous sandstone in irregularly alternating lighter and darker bands	338
Coarse gray sandstone	30
Banded argillaceous sandstone with Belemnites	300
Coarse gray sandstone with Belemnites	40
Banded argillaceous sandstone	56
Coarse gray sandstone and fine conglomerate	35
Banded argillaceous sandstone with several fossiliferous beds and a few thin bands of fine conglomerate	156
Somewhat massive dark-gray argillaceous sandstone with a few thin yellowish bands	150
Enochkin shales (see section on page 400).	
Total	5,139

This section is given in detail on account of the very great apparent thickness of the rocks referred to the Naknek formation. It is possible that a part of this thickness may be due to repetition of beds by faulting, though we were unable to detect any repetition and the faults seen did not seem to be important. Fossils are not abundant, but the characteristic Aucella resembling *A. pallasi* was found sparingly both near the top and near the bottom of the formation.

Section of Naknek formation on east shore of Oil bay, Alaska

	Feet
Naknek formation:	
Arkose, andesite, sandstone, conglomerate, and shale	2,000
Sandy shale with Aucella near base	600
Shale with fossils	380
Coarse sandstone	3
Shale with Cardioceras, Astarte, etcetera	165
Concealed	40
Sandstone and sandy shale with Lytoceras, Phylloceras, and plant impressions	310
Naknek formation (?):	
Agglomerate with an abundance of small pebbles, one-twelfth to one twenty-fifth of an inch in length, and with numerous poorly preserved plant impressions	7
Sandy shale and sandstone	85
Agglomerate with pebbles, as above	3
Shale	1
Fine agglomerate of same pebbles, as above	7
Fine agglomerate of same pebbles, as above, but interbedded with shale	14
Olive shale with an abundance of small pebbles, as above	30
Shale (Enochkin formation)	
Total	3,645

These exposures are shown in plate 68, figure 1.

Section of Naknek formation on east shore of Enochkin bay

	Feet
Sandstone, arkose, shale, andesite flows, and agglomerate	270+
Dark sandy shale, with Aucella in upper part	583
Coarse agglomerate	290
Shale (Enochkin formation)	...
Total	1,143

The coarse agglomerate forming the lower 290 feet of the last section is regarded as a local lens. It was also seen in the same position on Chisik island. The fine pebble agglomerate extending through a local thickness of 147 feet in the Oil Bay section is regarded as probably the representative of the coarser beds seen elsewhere. This section forms the upper two-thirds of the cliffs shown in plate 69, figure 1.

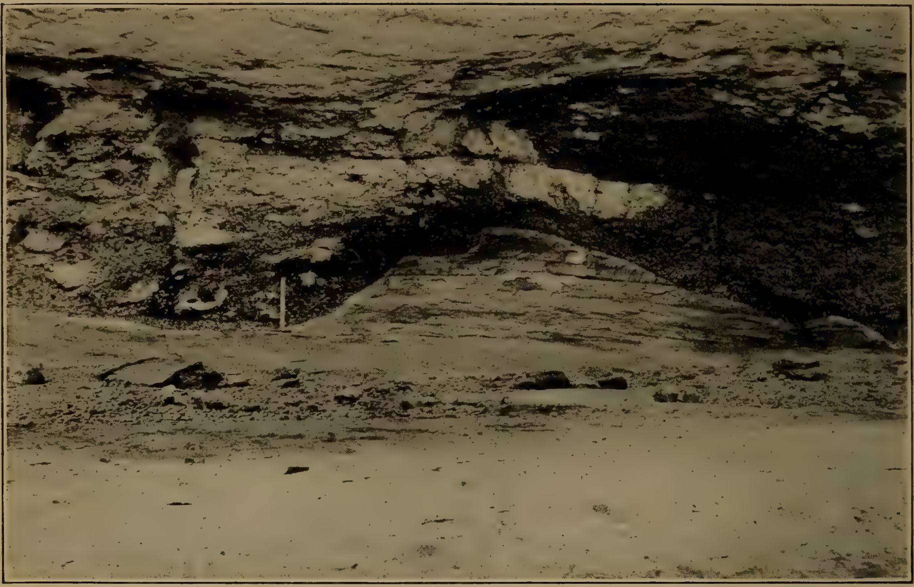

FIGURE 1.—UNCONFORMITY IN THE NAKNEK FORMATION, DOUGLAS RIVER, COOK INLET

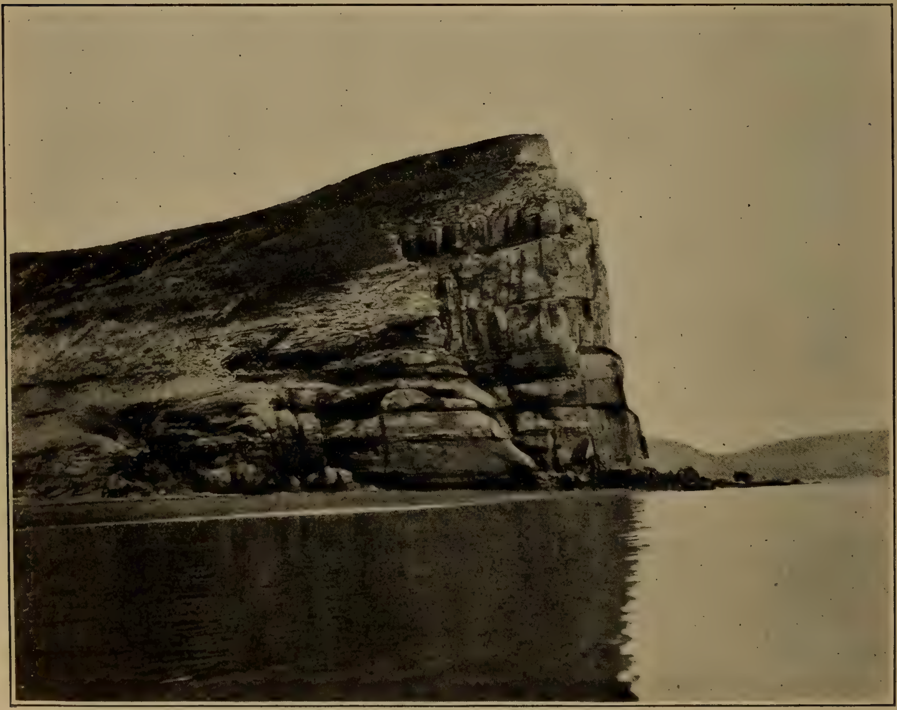

FIGURE 2.—CONGLOMERATE CLIFFS, NAKNEK FORMATION, COLD BAY, ALASKA

EXPOSURES OF NAKNEK FORMATION, ALASKA

In Kamishak bay the exposures of the Naknek formation are usually very fossiliferous sandstones, with low dip, and representing only a small part of the whole formation. One such exposure on Rocky bay is shown in plate 69, figure 2. On Douglas river, which empties into Kamishak bay west of Shaw island, there is an interesting local unconformity within the Naknek formation, showing an unevenly eroded surface, which was traced in the cliffs for about a quarter of a mile. The photograph (plate 70, figure 1) shows a detail of this exposure. The fact that the same fauna is found both above and below this unconformity is evidence that the erosion interval was geologically brief, and it probably did not affect a wide area.

The fauna of the Naknek formation is especially characterized by the presence of Aucella belonging to species very closely related if not identical with *A. pallasi* and *A. bronni* of the Russian Volga beds. These fossils are at some localities very abundant, completely filling thick beds. At other places they are so rare that they may be easily overlooked, but a careful search will find them in almost every section. Associated with the Aucella there are usually two or three species of Belemnites, frequently a large Lytoceras and a Phylloceras, and occasionally a few gastropods, Trigonia, and other pelecypods. At Oil bay the lower part of the formation yielded two species of Cardioceras related to *C. alternans* and *C. cordatus* which aid greatly in making more definite correlations with both American and European horizons. It is clear that the Naknek formation is of about the same age as the Mariposa beds of California with *Aucella erringtoni* and *Cardioceras* cf. *alternans*,* and it also includes the horizon of the marine Jurassic with *Cardioceras cordiforme* in the Black hills, where, however, the Aucella element is lacking from the fauna, and probably only the horizon of the basal portion of the Naknek is represented. A similar fauna occurs in Russia in the Volgian beds, and it is widespread in the boreal region, occurring on Spitzbergen, Nova Zembla, and elsewhere.

In Alaska, Aucella of the same type occur in the Kennicott formation of the Copper River region and at many places on the Alaska peninsula as far west as Herendeen bay.

LOWER CRETACEOUS

The presence of the Russian type of Lower Cretaceous on the Alaska peninsula is suggested by the occurrence of Aucella related to *A. crassicollis* at port Möller and Herendeen bay, where Jurassic types of Aucella also occur in other beds, but the details of the stratigraphy are unknown.

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* Two names, *C. whitneyi* Smith and *C. dubium* Hyatt, have been proposed for probably the same species in this formation.

These beds, with *Aucella* cf. *crassicollis*, comparable with the Upper Knoxville beds of California, are widespread in Alaska, though we found no indication of them at any localities studied by us. The species was obtained by Mendenhall on Bubb creek, a branch of the Taxlina, in the Matanuska series; by Spurr in the Oklune series on the Kanektok near the mouth of the Kuskokwim; by Schrader in the Koyukuk and Anaktuvuk series in northern Alaska, and by Wright on Admiralty island, southeast Alaska, where *Aucella piochi*, another Lower Cretaceous species, was found at a neighboring locality. It also occurs in the Mission Creek series on the Yukon. The geographic distribution of these Cretaceous Aucella beds is thus seen to differ radically from the distribution of the Naknek formation with its Jurassic Aucellæ, and this is regarded as evidence of a probable unconformity between them.

UPPER CRETACEOUS

On Chignik bay Upper Cretaceous rocks, closely associated with plant-bearing Kenai beds, occur on the lagoon 1 to 2 miles northeast of the Alaska Packers Association cannery and on Whalers creek, 5 miles west of the same place, where they apparently include a workable coal bed. The exposures at the first locality consist of several hundred feet of shales and sandstones with some thick beds of coarse conglomerate in the middle portion. The beds beneath the conglomerate contain great numbers of fossil plants, a collection of which yielded the following Upper Cretaceous species identified by Doctor Knowlton:

Osmunda arctica.
Sequoia reichenbachi.
Sequoia rigida.
Taxodium sp.
Torreya brevifolia.
Anomozamites schmidti.
Zamites sp.
Myrica sp.
Quercus johnstrupi.
Quercus n. sp.
Ziziphus sp.

The shales above the conglomerates yielded Inoceramus fragments, Pecten, *Nucula* (*Acila*) cf. *truncata*, Corbula, Thracia, Dentalium, Cinulia, and some undetermined ammonoid fragments.

At the locality on Whalers creek Mr R. W. Stone obtained an Inoceramus, related to *I. digitatus*, a Trigonia of the type of *T. leana*, and Anomia.

These fossils indicate correlation with a horizon in the Chico as developed in California and Vancouver island, which includes practically all of the Upper Cretaceous, but the beds at Chignik are probably not older than basal Senonian.

Beds of possibly the same age occur on the north shore of the small bay north of Aievak or Douglas village, where there is a series of shales and sandstones with an estimated thickness of 2,000 feet, from which fragmentary specimens of a large Inoceramus and a Desmoceras (?) were obtained.

Pompeckj, who restudied the old collection of Wosnessenski from near Katmai, reports a specimen of Belemnitella labeled as coming from that place, and on that account infers the presence of Upper Cretaceous there, but this lacks confirmation.

The Cretaceous beds at Chignik may be directly correlated with those on the Yukon near Nulato, and less certainly with those on the Anaktuvuk, in northern Alaska, which are the only occurrences of Upper Cretaceous hitherto reported in the territory.

It is probable that more detailed study will reveal considerable areas of Upper Cretaceous rocks on the Alaska peninsula, but their recognition in rapid reconnaissance is made difficult by the fact that lithologically they resemble the Eocene Kenai beds of the same region, which, like the Upper Cretaceous, are coal-bearing and contain fossil plants of similar general types. The relations are further obscured by frequent faults, so that paleontologic evidence is necessary for the identification of the formations in each area; but fortunately both the plants and the animals of the Cretaceous are easily distinguished from those of the Kenai when sufficient collections are obtained. There are doubtless unconformities both below and above the Upper Cretaceous of this region, since all of the Lower Cretaceous is lacking at most localities, and at some places the Kenai rests directly on the Jurassic.

RÉSUMÉ

The Mesozoic section of southwest Alaska includes representatives of the Upper Trias, Lower, Middle, and Upper Jurassic, Upper Cretaceous, and probably Lower Cretaceous.

The Jurassic shows the greatest development, both stratigraphically and faunally, and is probably unequaled in these respects elsewhere on the American continent. The total thickness can not be much less than 10,000 feet, and the areas covered by the upper half of the Jurassic are large.

The faunal type is essentially Russian—that is, boreal, though it differs in the common occurrence of Phylloceras and Lytoceras at several horizons. The succession of the faunas from the Callovian to the top of the Jurassic is the same as in Russia, but the vertical thickness of beds through which each ranges appears to be very much greater in Alaska.

The Cretaceous and Triassic rocks so far as now known occur only in small scattered areas, and their faunas may be directly correlated with those of formations in California and elsewhere on the Pacific coast.

The general relations of the formations may be epitomized in the following section:

Tertiary.—Kenai formation. Shales, sandstones, and conglomerates with several beds of coal. The entire formation non-marine and characterized by a large flora. Thickness, ± 2,000 feet.

Unconformity.

Upper Cretaceous.—Lithologically similar to the Kenai, but including some marine shales and sandstones with an Upper Cretaceous fauna. Thickness, ± 1,000 feet.

Unconformity.

Lower Cretaceous.—(Not seen within the area studied.) Shales and sandstones with *Aucella crassicollis.*

Unconformity ?

Upper Jurassic.—Naknek formation. Conglomerate, arkose, sandstone, and shale with interstratified andesite flows. Thickness, about 5,000 feet.

Middle Jurassic.—Enochkin formation. Shales and sandstones with some conglomerate beds. Thickness, 1,500 to 2,500 feet.

Unconformity ?

(Possibly conformable on Lower Jurassic when that is present.)

Lower Jurassic.—Tuffs and sandstones. Thickness, ± 1,000 feet.

Unconformity.

Upper Triassic.—Thin bedded cherts, limestones, and shales usually much folded and contorted and with many intrusive masses. Thickness, ± 2,000 feet.

Base not seen.

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GEOLOGICAL BOOK-KEEPING

BY J. F. KEMP

(Read before the Society December 29, 1904)

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INTRODUCTION

So long as a geologist is in the field for a short and continuous period and in a restricted and comparatively simple district, no more elaborate and systematic system of notes is needed than is afforded by a map and a book. But when the district becomes complex and difficult, as in many metamorphic areas, and when the field work extends through several seasons, often with intervals of a year or two between, some method of indexing and compiling becomes absolutely necessary. The best of memories can not carry the endless details involved, and during office work time can not be spared for the discouraging search through a number of note books. A system that will work almost automatically is as essential to the geologist as is double-entry book-keeping to a large commercial house, and it fills very much the same field.

If, moreover, a teacher has to give field instruction to rather large parties in structural and areal work, it is almost as essential to have some uniform method in accordance with which all will record their observations and coördinate them one with another. From experience of both these kinds the writer has been led to evolve the plan here set forth and has found that it answers satisfactorily and adds greatly to efficiency. It is also quite evident that were this or something like it in general use by state surveys, it would, as years go by, save much useless repetition of field observations. A later worker might then inherit and understand the observations of one or more predecessors.

The first essential of satisfactory field work is a map, and now that the topographic sheets of the United States Geological Survey are becoming so numerous and widely distributed they can be taken as the basis of work in all parts of the country. They will therefore be assumed as the foundation of the system, although it will apply to any map. The subject may be best set forth under two heads: The field map and note book, and The compilation book.

The Field Map and Note Book

The usual methods of employing maps and locating observations, so far as the writer can learn, are the following: The note book being ruled in squares, a suitably sized piece of the map is pasted upon a page so that locations can be made, as in atlases, by a row of letters across the top and numbers down the sides. Between intersecting horizontal and vertical lines any special point may be noted. With numerous and closely set observations this system does not admit of great accuracy, and it is difficult to locate oneself accurately when away from the sides and top of the sheet.

According to another method, the observer, when setting out from a base or center of operations, draws a line on the map showing his course, and upon this marks consecutively numbered stations where specimens or notes are taken. This is very accurate, but in detailed work it leads to a confusing multiplicity of lines, and does not work up to systematic compilation as an end-result.

In the method here set forth the usual topographic sheet is lightly ruled with waterproof india ink in squares of a mile or two miles on a side according as the scale is $\frac{1}{62\cdot500}$ or $\frac{1}{125\cdot000}$. This gives useful areas in estimating size and distance. Each second vertical and horizontal line is drawn double, so that the double lines enclose four squares of single lines. At the intersection of the single lines numbers are written, also in waterproof india ink, and in this invariable order:

Beginning in the upper left-hand corner the numbers 1, 2, 3, and so on to 7, are written at the intersection of the single lines, as shown in figure 1, so far as it goes across. Below 1, 11 is put on the next row, and so on across, 12 running under 2, 13 under 3, etcetera. The next row begins with 21, and is all in the twenties, and so on to 81 and other eighties along the bottom row. This makes an invariable decimal system.

The four squares around each number are now themselves numbered in an invariable order, as shown in figure 1, but these numbers are not placed on the map, since it requires no effort to recall that the northwest square is 1, the northeast 2, the southwest 3, and the southeast 4. We thus have a system by which each square has its own number, as 1, 2; 43.3; 61.4, etcetera. Each square is now subdivided into ninths, and the ninths are enumerated, as shown in square 12.1 of figure 1. They are not put down on the map, however, as it is easy to estimate them.

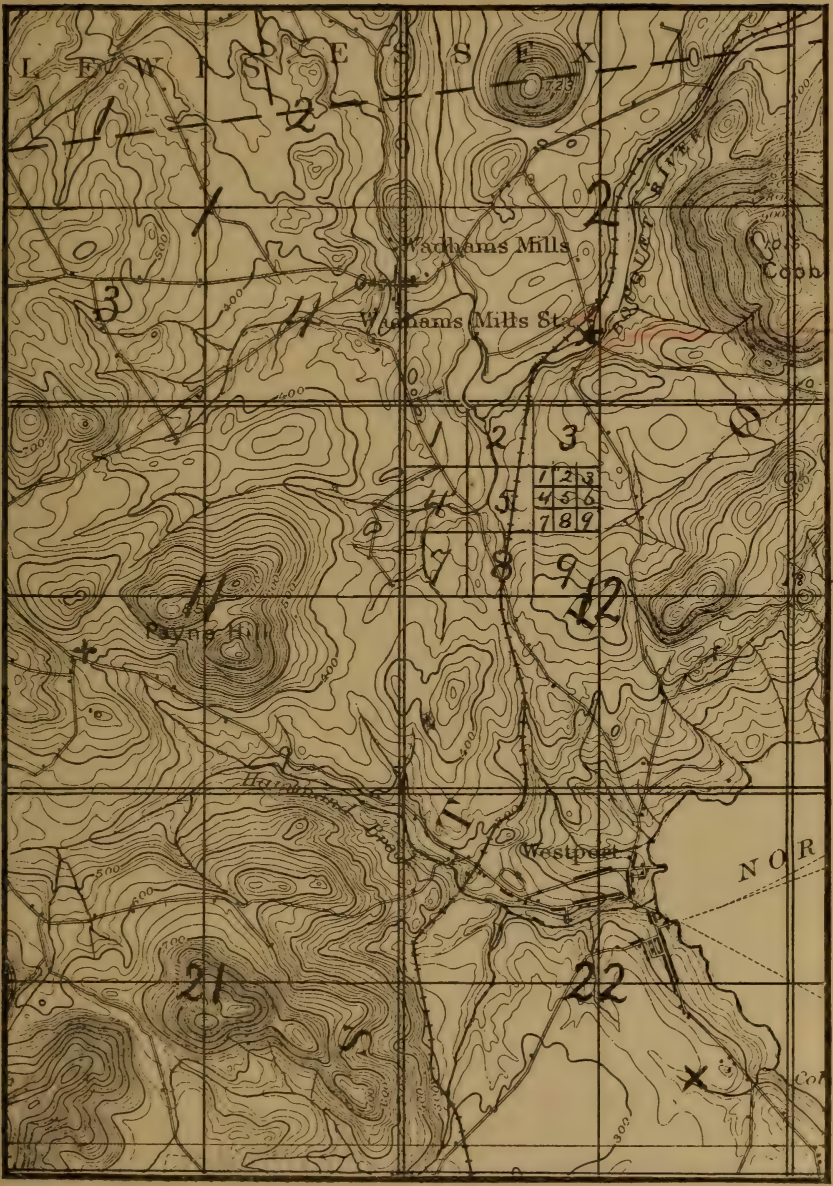

L E W I S
E S S E X
1
2
3
4
7
8
9
11
12
21
22
Wadhams Mills
Wadhams Mills Sta.
Payne Hill
Westport
N O R
723
500
600
700
300

FIGURE 1.—*Northwest Corner of the Port Henry, New York, Quadrangle.*

Illustrating method of recording notes. In a full U. S. Geological Survey topographic sheet the numbers would read 7, 17, 27, etcetera, in the right vertical column, and 81, 82, etcetera, to 87 below, in the lowest horizontal row.

The use of ninths also keeps us within the limits of single digits. For greater accuracy each ninth may now be considered to be divided into other ninths, as shown in 12, 1.6, and beyond this it is almost never necessary to go. The star (*) on the map, figure 1, is in 2,369 (read, two, three, six, nine). The plus sign (+) is in 11,327; the multiplication sign (×) in 22,455. In the note book one would merely record 11,327 and the observation, after placing a dot or little cross on the map.

For field use the maps, after being drawn with squares, should be trimmed of the borders to the quadrangular lines and cut in thirds along the parallels of latitude. Each strip is then doubled back on itself once, map side out, and folded forward in quarters, map side in, so as to make a little accordion-like book, which can be tied in the note book and turned over like the leaves of a book. On the back of each should be written the name of the quadrangle, and "north third," "middle third," and "south third," as the case may be, and the year or years in which the maps were used in the field.

When ruled in squares of this size there will always remain except in a few fortunate latitudes a strip at the right side of the map which does not make an even inch. Latitudes 41 degrees 30 minutes to 42 degrees, for example, are almost exactly divisible, but those to the north and the south are not. There will also always remain at the bottom of the map an incomplete lower row about half a square high, and in the eighties. These fractions, however, cause no difficulty, because the proper numbers of the parts remaining are perfectly apparent and the others simply drop out.

In cutting up the maps into three strips along the parallels of latitude other squares are cut into fractional parts, but this also occasions no serious trouble, because the order of enumeration being invariable, if we have the numbers of one row before us, those of all the others adjacent are at once apparent. Thus in figure 1, in the fractional strip on the right, we can locate ourselves just as well from the column of the squares, 2, 12, and 22, as if we actually had the appropriate numbers, 3, 13, and 23, which are cut off.

As a variation and perhaps as an improvement upon the above method of drawing the squares, it is, of course, possible to place the double lines at intervals of three squares, so that each square of double lines encloses nine of single lines, then number in the same way and go down to any desired accuracy by subdivisions of ninths. Or it is possible, as the sheets are all divided into nine parts by the intersections of the meridians and parallels, to make the rectangles, thus afforded, the basis of the primary numbering and then go down by ninths, never needing double figures for the large unit area, but this latter plan throws us out of the mile-on-a-side squares which are very useful scales of distance.

Figure 2 illustrates one-ninth of the same quadrangle which is used for figure 1. Its northwest corner is at the intersection of latitude 44 degrees 15 minutes, with longitude 73 degrees 30 minutes. As the quad-

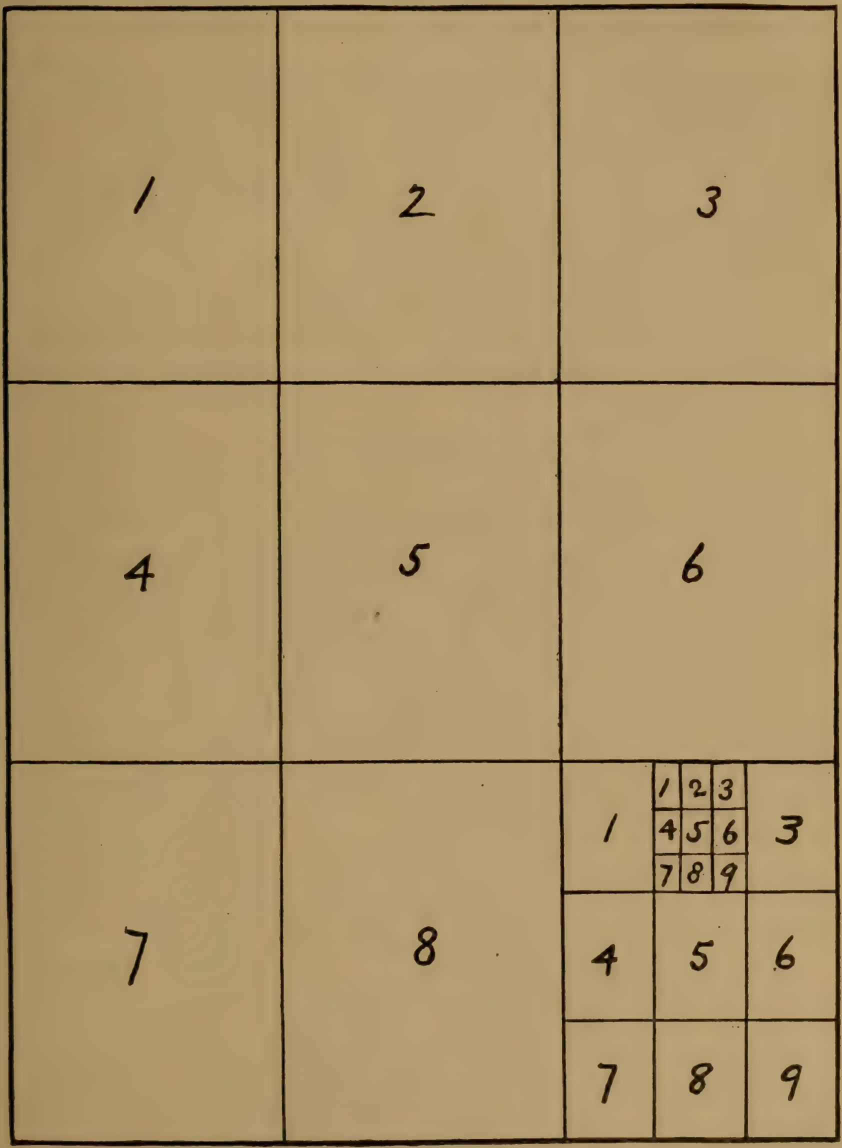


FIGURE 2.—*One-ninth of a United States Geological Survey Topographic Sheet in Latitude 44.*

The ruling is designed to show the coordinate method by ninths.

rangles are situated farther south, the east-and-west dimensions widen appreciably, and for those farther north they become more narrow. With the increasing width the ninth of the fourth dimension becomes larger and it may be desirable to add a fifth ninth. This, however, goes automatically, and it is slight trouble to use the additional digit. The variability of the east-and-west spaces makes it necessary to refer to the scale of each sheet in order to use the subdivisions as scales of actual distance, but should the method receive any extended adoption it would be a great convenience to field workers if the United States Geological Survey would print upon the map for those who wished light surcharges of rectangular ninths of the second dimension, the 5 minutes of longitude and latitude in the scale $\frac{1}{62.500}$ forming the ninth of the first dimension. For surcharges of this sort a series of squares, such as a mile on a side and having an invariable size, would be much less expensive and more convenient than one whose size varied with every 15 minutes of latitude, and therefore the writer favors the use of those a mile on a side and in blocks of four.

The Compilation Book

For the compilation book a blank book is selected of convenient size, and preferably a standard one, which can be always obtained of the dealers. It is then paged in a series corresponding to the squares, usually 1.1; 1.2; 1.3; 1.4; 2.1; 2.2; 2.3; 2.4; 3.1, and so on, to 87.3 for the first method of squares, or up to 9.9.9 for the last one. Now, taking the field book day by day, the notes are copied into the compilation book, each on the page corresponding to its square. At the top of page 1.1 is put the observations in 1.1.1; and if 1.1.9 is first met in transcribing the field notes, its record is placed at the foot. Intermediate ones are interpolated at intervening points as nearly as the compiler will estimate their serial location. Note books should all be numbered in series and paged. Two compiled notes may then read as follows:

1.1.7.5. B.26, 117, Gabbro-gneiss N. 70 E. 45 N. Spec. 261. Becomes massive 100 paces north. Glacial scratches N. 60 E. and N. 40 E., former older. Trap dike, 4 ft. wide. N. 45 W. Spec. 262.

1.1.8.9. B.45, 23, Beekmantown l. s. 40 ft. exposed. N. 50 W. 10 E. Silicious, no fossils. Glaciation!! N. 60 E.

From the first we know that in this particular square, as recorded in note book number 26, page 117, gabbro-gneiss occurs, with the strike and dip given, and with the associated phenomena subsequently recorded. The significance of the record for the next square is apparent. When the field work is completed in a quadrangle or any part of it, all the observations ever taken on any square, no matter if years have intervened, are recorded upon one or two pages, and are available for use in drawing a map.

In the office, therefore, and with a fresh map ruled in squares, the geologist begins with 1, 1.1, and plots in the geology square by square. Having a series of empty drawers at hand, the specimens are assembled as the work progresses, and grouped by narrow localities in an easily intelligible way. Should he desire to refer to the original note book and field map, he does so instantly. If, moreover, one merely turns the leaves of a compilation book, it is possible to note by the blank, or sparsely written pages, where observations fail or are few. Revision or amplification follow, if necessary, as a matter of course. Should the observations be sufficiently detailed, they are available for sections at any points and in any direction. It is also advantageous to select a compilation book with sufficiently abundant pages, so that at the back petrographical or other office notes may also be included, and everything be thus kept together. For convenience of reference a fresh map is ruled, folded, and fastened in the compilation book, the field maps being left in the note book. Finally, from the first rough map the finished one, which is to go with the final report, may be drawn with colored inks and a right line pen.

Where large classes of rather numerous squads of two each are taught in the field, the compilation book can be passed from squad to squad, each pair writing in their notes. Finally, the record being complete, each squad can use the compilation book in preparing a final report and drawing a map of the whole district. With a party of ten or fifteen pairs located in a quadrangle which has been mapped on the scale of $\frac{1}{62 \cdot 500}$ and which is suitably provided with means of transportation, within a week or ten days and within the limits of skill of younger workers, the whole area will be overrun in the greatest detail and almost every outcrop duly mapped and recorded. Areas are assigned square by square, reported on systematically to the instructor in the evening, and colored in on a compilation map. The students see the results gradually assuming definite shape, and great interest is usually aroused in the final result. When such compilation books are kept on file in an institution or placed with a state geologist, they would be of much permanent value.

Principles on which the System is Based

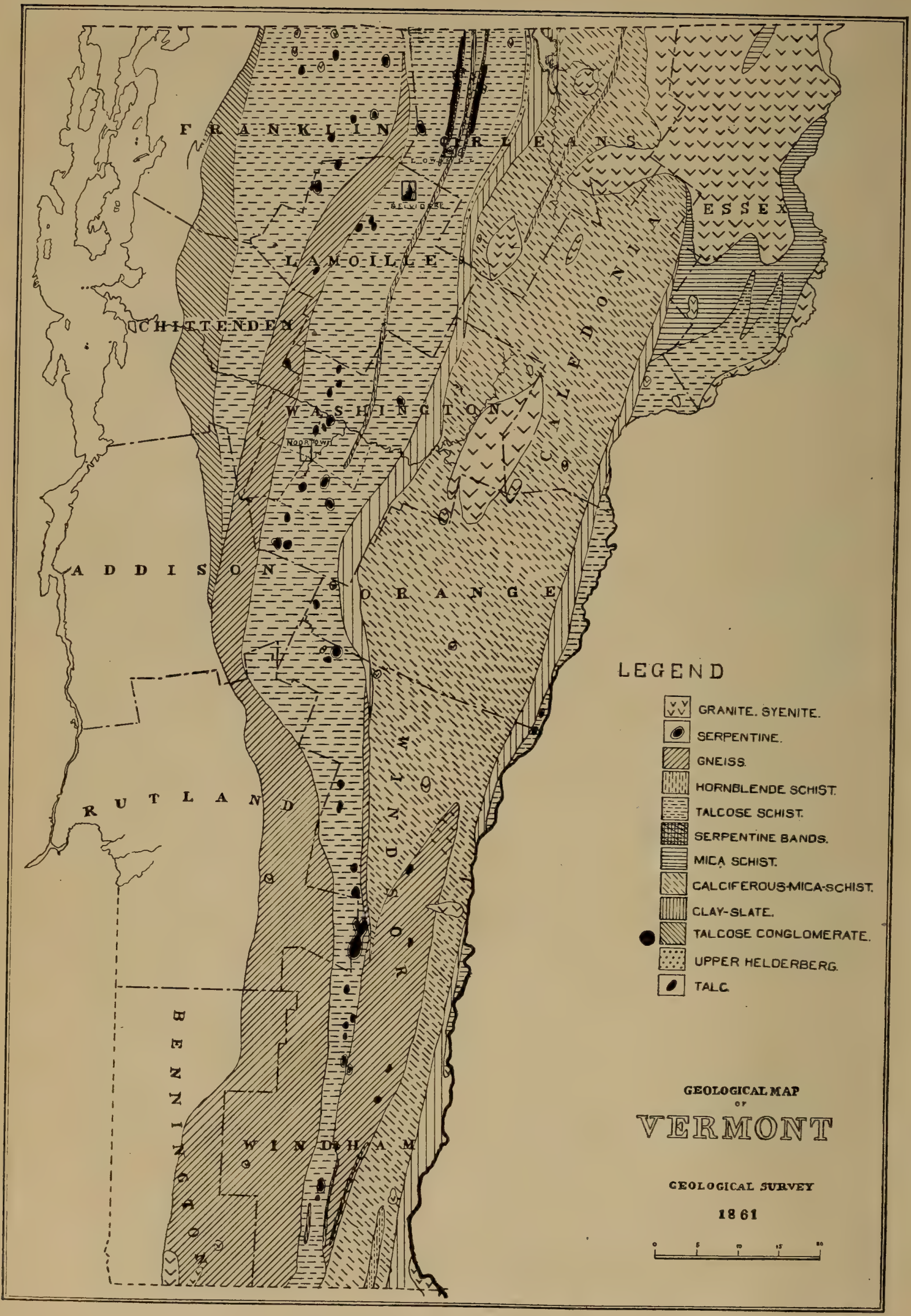
The above system is based on the principle of locality for the orderly entry of observations. Reflection on the subject by any experienced geologist will soon develop three possibilities: First, one may not compile at all, depending on the memory as a guide to the notes distributed through several field books. The field books may be esteemed of purely ephemeral value, to be discarded after the final map and report are prepared. It may be and usually is assumed that they will be of no further use and will never be consulted by another or subsequent observer. It is true that field books are often only intelligible to those who write them, and, as usually recorded, a later reader without the personal guidance of the original recorder would have difficulty in intelligibly following a traverse with numerous observations; yet the field book is necessarily the most detailed of all the records, and provided it is intelligible, it contains what is of greatest value to a subsequent worker. Its weak point is the frequent lack of a systematic, simple, elastic, and uniform method of recording locations, since, if the writing can be read at all, the uncertainty alone arises from the location of the observation.

Over this method the system here set forth certainly has advantages both in the field and in the office.

The second principle on which observations may be systematically grouped is that of time. An observer who makes no index or compiled summary usually, when trying to recall what he has seen in a particular locality or region, does so by running back in his mind over his movements in various years and months until in this way he can establish the particular note book which is sought, yet as note books accumulate this process is slow and tedious and often elusive. As compared with it a method based on locality is much to be preferred. If note books are indexed or provided with a table of contents, the search is simplified, but even then, should a searcher wish to know everything which he or his colleagues or predecessors had observed in a certain square mile of a certain quadrangle, it would be a slow process to find this information by any scheme, however well indexed, if based on the time principle.

The third principle is that of locality, and is the one suggested in this paper. So far as the accurate recording of observations is concerned, other methods may be as good as this one, perhaps even better, but none lead up to the compilation book, which is the great saver of time and effort. So long as a spot or a square mile or any larger area can be located on a standard map one can turn in a moment to a compilation book and find the condensed records of all observations, and, if the plan is systematically carried out, not only of one, but of many observers. The detail and completeness of the work is at once apparent and the progress of knowledge much facilitated.

The principle of locality has, finally, incomparable advantages, because, so far as areal geology is concerned, observations are alone of value when accurately tied up with a definite place.


FRANKLIN
ORLEANS
ESSEX
LAMOILLE
CHITTENDEN
CALEDONIA
WASHINGTON
ADDISON
ORANGE
RUTLAND
WINDSOR
BENNINGTON
WINDHAM
BELVIDERE
LOWELL
ROXBURY
LEGEND
GRANITE. SYENITE.
SERPENTINE.
GNEISS.
HORNBLENDE SCHIST.
TALCOSE SCHIST.
SERPENTINE BANDS.
MICA SCHIST.
CALCIFEROUS-MICA-SCHIST.
CLAY-SLATE.
TALCOSE CONGLOMERATE.
UPPER HELDERBERG.
TALC.
GEOLOGICAL MAP OF VERMONT
GEOLOGICAL SURVEY
1861
0
5
10
15
20

GEOLOGICAL MAP OF VERMONT

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PETROGRAPHY OF THE AMPHIBOLITE, SERPENTINE, AND ASSOCIATED ASBESTOS DEPOSITS OF BELVIDERE MOUNTAIN, VERMONT*

BY VERNON FREEMAN MARSTERS

(*Presented before the Society December 30, 1904*)

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* In the field work on which this paper is based I beg to acknowledge the hearty cooperation of Professor G. H. Perkins, state geologist of Vermont, as well as the assistance of Judge M. E. Tucker, whose detailed and accurate knowledge of the area, gained during his search for asbestos rock, was cheerfully placed at my service. To Mr B. B. Blake, of Eden corners, and Mr Silsbey, of Lowell, I wish to express my thanks for assistance freely given in that portion of the area with which they are fully acquainted.

In the investigation of the petrographic problems involved I beg to acknowledge the invaluable assistance and many suggestions offered by Professor J. F. Kemp, Dr C. P. Berkey, and Dr A. A. Julien, of Columbia University.

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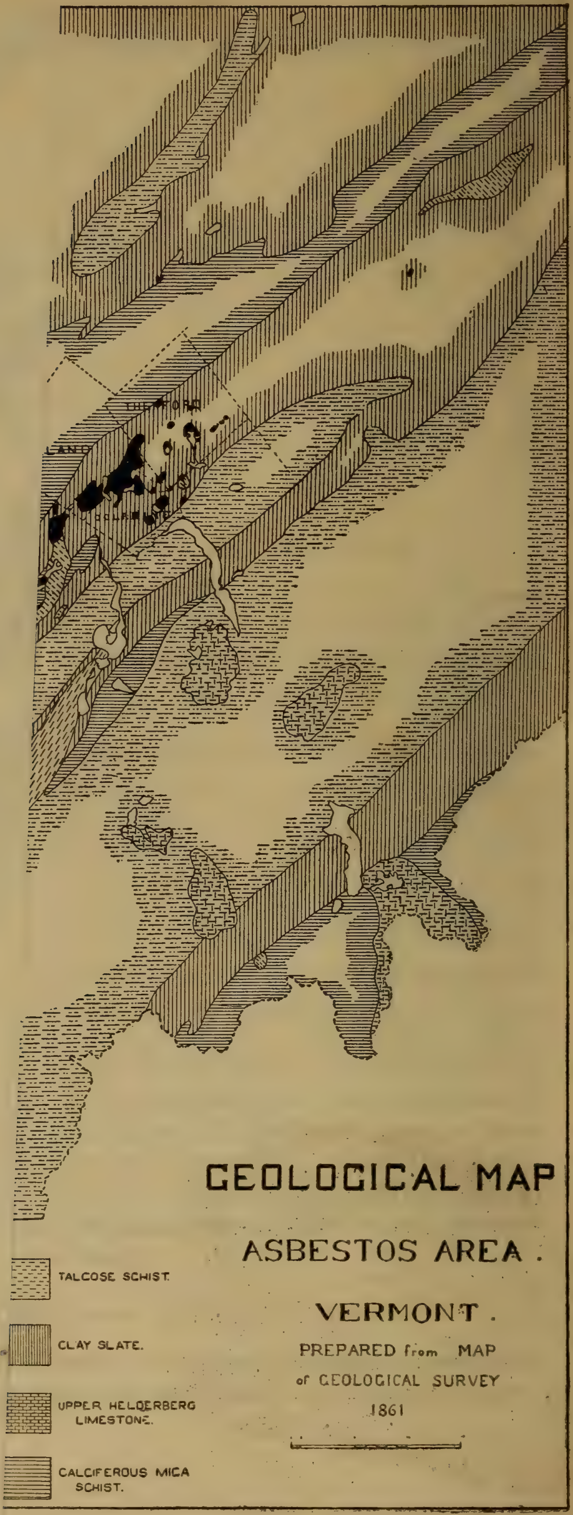
EARLY VIEWS ON THE STRATIGRAPHY OF VERMONT

The occurrence of serpentine and associated minerals was early known to the pioneer geologists of Vermont. In the report prepared by Professor Edward Hitchcock and his co-workers (1861) frequent mention is made of them, and it is stated that in many instances more or less asbestos and talc, in several varietal forms, are to be found. While considerable preliminary prospecting was carried on in the early seventies, no industry of any moment was established until a comparatively late date.

According to the observations of Professor Hitchcock, the serpentine formations are very largely confined to a broad band of so-called talcose schists which enters Vermont on the north in Orleans county. At the northern boundary of the state the schist belt has a maximum width of some 15 miles, with its eastern limit near the western shore of lake Memphramagog. This series of metamorphics is shown on his map as extending the entire length of the state and occupying portions of Orleans, Lamoille, Washington, Addison, Orange, Windsor, and Windham counties and having a minimum width at the southern boundary of the state of some 2½ miles. While some ten occurrences of serpentine are reported to exist in the southern half of the talcose belt, by far the largest of these deposits is located in Orleans and Lamoille counties. It is very probable that this serpentine and the associated schists belong to the same group as those of the Thetford region. The schists are regarded by the Canadian Geological Survey as Cambrian in age.

LOCATION OF BELVIDERE AND LOWELL AREAS

The small area under consideration in this paper lies within the adjoining townships of Eden, in Lamoille, and Lowell, in Orleans county.


THETFORD
LAND
COLERAINE
GEOLOGICAL MAP
ASBESTOS AREA.
VERMONT.
PREPARED from MAP
of GEOLOGICAL SURVEY
1861
TALCOSE SCHIST.
CLAY SLATE.
UPPER HELDERBERG LIMESTONE.
CALCIFEROUS MICA SCHIST.

IN QUEBEC AND VERMONT

According to the Hitchcock map, the serpentine bands, of which two are reported, terminate near the central part of Lowell township; the west one, however, is represented as extending a little south of the village of Lowell. In Eden township no serpentine is represented. There is, however, in Eden, and continuing in Lowell, a most interesting area of these magnesian rocks, forming the southern slope of Belvidere mountain, and a plateau-like projection to the south and east of the mountain crest. This may be designated as the Belvidere area (see map, figure

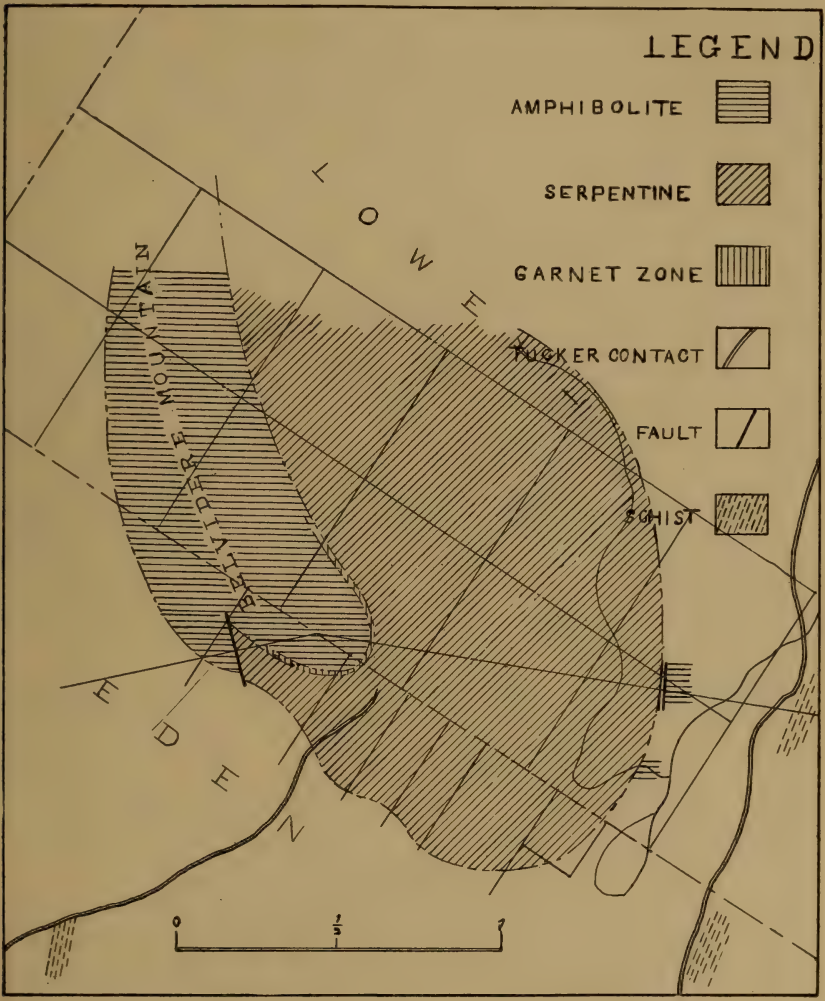
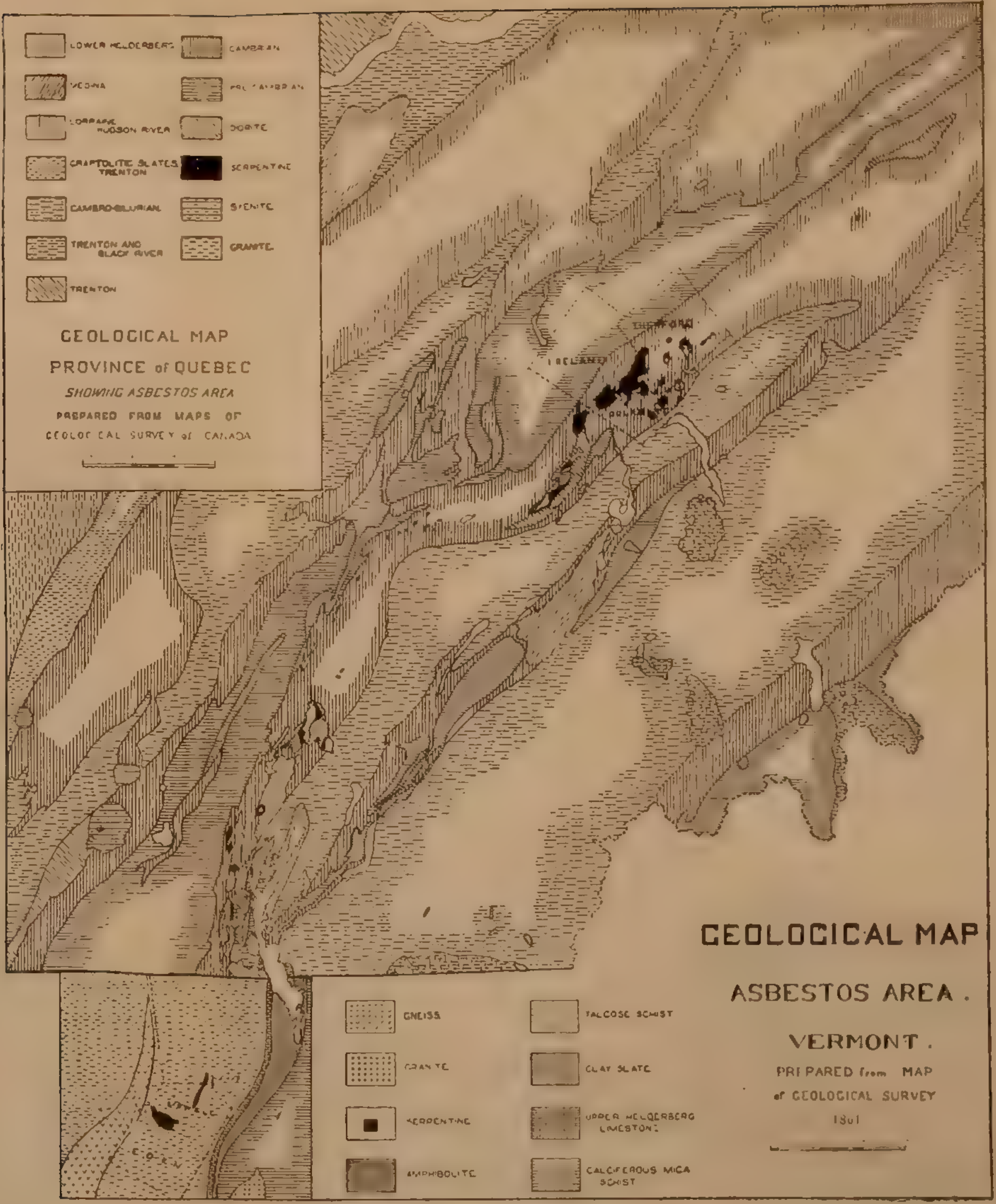

LEGEND
AMPHIBOLITE
SERPENTINE
GARNET ZONE
TUCKER CONTACT
FAULT
SCHIST
LOWELL
EDEN
BELVIDERE MOUNTAIN
0
1/2
1

Figure 1.—*Geological Map of Belvidere Mountain.*


LOWER HELDERBERG
MEDINA
LORRAINE HUDSON RIVER
GRAPTOLITE SLATES TRENTON
CAMBRO-SILURIAN
TRENTON AND BLACK RIVER
TRENTON
CAMBRIAN
PRE-CAMBRIAN
DORITE
SERPENTINE
SYENITE
GRANITE
GEOLOGICAL MAP
PROVINCE of QUEBEC
SHOWING ASBESTOS AREA
PREPARED FROM MAPS OF
GEOLOGICAL SURVEY of CANADA
THETFORD
IRELAND
GNEISS
GRANITE
SERPENTINE
AMPHIBOLITE
TALCOSE SCHIST
CLAY SLATE
UPPER HELDERBERG LIMESTONE
CALCIFEROUS MICA SCHIST
GEOLOGICAL MAP
ASBESTOS AREA.
VERMONT.
PREPARED from MAP
of GEOLOGICAL SURVEY
1861

GEOLOGICAL MAPS OF ASBESTOS AREAS IN QUEBEC AND VERMONT

1). So far as the data at hand bear on the question as to the limits of the area, it is to be said that all field facts strongly suggest that it is not connected with the belt passing through Lowell village.

ECONOMIC IMPORTANCE OF SERPENTINE

Apart from the scientific interest in the origin and development of the serpentines, they are also of special economic importance, inasmuch as a considerable amount of asbestos is known to occur within the limits of the region under consideration. Small lenses of talc, too, are not uncommon within the central part of the Belvidere area, as well as in the Lowell belt, but the asbestos is by far the more important economic product of the two. It should be added, however, that it does not follow that talc is always of secondary importance in serpentinous rocks. On the contrary, in the region of Moretown, Washington county, large talc deposits are being opened and a mining plant is in process of construction. In this case, so far as can be determined from the preliminary prospecting, asbestos-like minerals are quite secondary to the development of talc. The talc appears to occur near the contact of serpentinous rock, with talcose and micaceous schists or as small lenses within the serpentine. It is not improbable that careful prospecting within the limits of the Moretown area may bring to light other talc deposits of sufficient economic importance to form the basis of a small but profitable industry.

TOPOGRAPHY OF BELVIDERE REGION

Topographically this region consists of a series of valleys and ridges having a general northeast-southwest trend. Near the west corner of Lowell lies Belvidere mountain, a sharp-crested ridge, with its highest point at its southern extremity and within a few rods of the Lowell-Eden township line. The eastern side of Belvidere is shown in the accompanying photograph. The altitude of the crest gradually decreases to the north. A steep-sloped valley, locally known as Hazens notch, in the southwest corner of Westfield, separates Belvidere from the ridge to the north. Hadley mountain is separated from Belvidere by the west branch of the Missisquoi river. From its northern flank a low spur extends to and beyond Lowell village, where it is crossed by Johns branch, a tributary to the Missisquoi. A part of this spur is locally known as the Leland hills. In the southwest corner of Lowell are the so-called Lowell mountains, with the same general trend as Belvidere.

The greatest altitude of Belvidere is approximately 2,100 feet above Eden corners and some 1,200 feet above the office of the New England

Mining and Development Company. The upper half of the ridge presents exceedingly steep cliffs, occasionally alternating with talus slopes and "slides" containing enormous blocks of rock, the form of these masses being due to the development of two well defined sets of joints. To the north, however, the steepness of the slopes gradually decreases, and a cover of waste extends well up the flanks. At the south end of Belvidere a somewhat crescent-shaped plateau rims the south and southeast sides. This topographic element is largely composed of serpentine, the level portion being comparatively free from drift or talus, except along its upper edge and again at its foot, where it is in part covered up by sand or gravel deposits, forming terraces on the bottom and along the lower part of the Missisquoi valley. A typical view of the outer slope of the serpentine plateau, as well as the valley at its foot and the eastern ridges of the Green Mountain series, is shown in the accompanying photograph. The gradual extension of the glacial deposits up the slopes to the north and their coalition with the debris from above, the whole being covered with a dense forest, renders the lithologic relation-

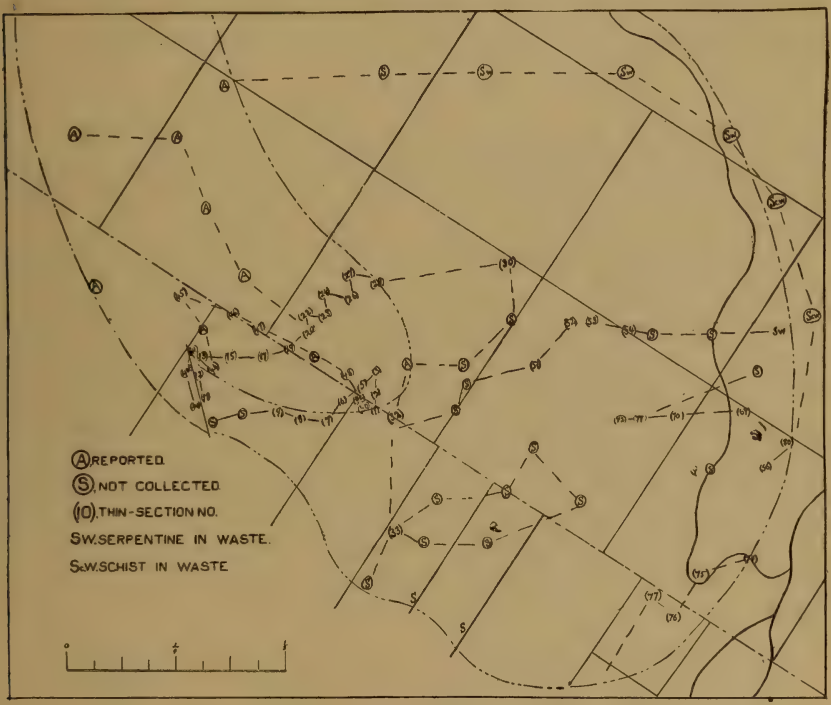


FIGURE 2.—*Traverse Map of Belvidere Mountain.*

ships of the area between the plateau and Hazens notch very difficult to ascertain.

Rock Types

GENERAL DISTRIBUTION

Within the area under consideration three widely different types of rock are to be found, namely, schist, amphibolite, and serpentine. The first occupies the valley floors and lower slopes of the Missisquoi; the second forms the uppermost 1,000 feet of Belvidere mountain, and the third occupies the area between the schist and the amphibolite.

SCHISTS

Brief discussion of composition.—It will be seen from an inspection of the map showing the distribution of a part of the formations of the state that the Belvidere area lies entirely within the so-called talcose schist as mapped by Hitchcock and published in the report for 1861.*

On account of the lithological characters and mineralogical associations the schists of Vermont were early regarded by Hitchcock and others as a part of the great terrane extending from southeastern Canada (Quebec) to Alabama. Among the first scientific men to devote attention to these peculiar rocks was T. Sterry Hunt, who carried on a series of chemical investigations with the hope of gaining some knowledge of the origin of this rather prominent series of metamorphics as they appear within Canadian territory. His studies led to the conclusion that they were derived from slates. His chemical results, moreover, brought out the fact that the name "talcose" as applied to the schists was a misnomer. This fact is evident from an inspection of his analysis, which is appended:

Silica	66.70
Alumina	16.20
Peroxyd of iron	6.90
Lime	.67
Magnesia	2.75
Alkalies (by difference)	3.68
Water	3.10
	100.00

Thus it is seen that less than 3 per cent of magnesia is to be found in this sample (Saint Marie), and even in the slates with which the talcose schists are closely associated not more than 8 per cent. It is thus evident that, in so far as the Canadian representative is concerned, the above term is not at all applicable.

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*Edward Hitchcock: Geology of Vermont, vol. 1, p. 504. Map, vol. 2.

The announcement of these results stimulated further study of this same problem within the limits of Vermont. The investigations of Mr G. H. Barker under the directions of the state survey produced similar results. The specimens analyzed came from Roxbury, Pownal, and Middlesex respectively.

The name "talcose" as applied to the Vermont schists is also an unwarranted term, although it is to be said that talc and talcose lenses are not uncommon within the limits of the schist formation.

Age of the schists.—As to the age of the schists, various interpretations have been offered. If I am correct in correlating the schists, with which the asbestos-bearing serpentines are associated in Quebec, with the occurrence under consideration, the Vermont series would be regarded by the Canadian geologists as belonging somewhere in the Quebec group.

The term "Quebec" is applied to a large series of metamorphics, including slates, schists, and serpentine deposits. It is probable that it, in reality, included both Cambrian and pre-Cambrian rocks. Moreover, the occurrence of graptolites within the limits of the Quebec group also shows that it includes rocks of Ordovicic age as well. Where in the series the schists and the associated serpentines belong is not yet clear from the evidence at hand. It has been stated by the Canadian Survey that the schists are in all probability Cambric in age.

The southern extension of the schists, as represented in Old Hampshire county, Massachusetts, and Windham county, Vermont, has been studied in very great detail by Professor Emerson. Using the Vermont geological map as the basis for comparison, the talcose schists of Vermont are continuous with the Goshen schists of Franklin and Old Hampshire counties. This terrane is considered as Siluric by Emerson. Inasmuch, however, as the United States Geological Survey did not adopt the term "Ordovicic," as suggested by Lapworth, for Lower Silurian in the nomenclature of geologic folios until this year, it should be noted that the term "Silurian" as used by Emerson probably includes rocks of Ordovicic or possibly earlier age. If this interpretation be correct, it is clear that the Quebec group of the Canadian Survey and the Silurian as used by Emerson may overlap or include one or more formations of one and the same age—that is, the upper members of the former may be synchronous with the lower members of the latter; but to what extent they may be chronologically parts of the same formation can not be determined with the data at hand. Such evidence as can be obtained from the literature suggests that the Vermont series may be the late Cambric or early Ordovicic in age.

AMPHIBOLITES

Areal distribution.—An inspection of the map of the Belvidere region will show that the main area of amphibolite is confined to the uppermost 1,000 feet of the mountain crest at the southern terminus of the ridge. This rock probably makes up the tip of the ridge as far as Hazens notch ; how far it may extend beyond has not been determined.

Small but important exposures of the same rock occur at the lower edge of the serpentine and in prospects opened up by Judge Tucker. There are thus three areas ; but the two smaller ones are particularly important, inasmuch as they provide certain data which it is believed will make clear with reasonable certainty the true lithological relationships of the amphibolite and the serpentine and the origin of the latter.

At the south end of Belvidere the amphibolite forms the steep sloped portion above the plateau-like terrace, as seen in the accompanying illustration (plate 73, figure 1).

Macroscopic characters and mineral composition.—A very large portion of the rock is composed of dark-green hornblende, so arranged with respect to the cleavage of the individual components that a gneissic and, at times, a decided schistose structure is fairly well defined. At the base of the hornblendic mass, or just above the level of the rimming plateau referred to, the amphibolite presents an additional phase in becoming highly garnetiferous. The relation of the garnet-bearing zone to the underlying serpentine is not easily determined, as the probable contact is covered by waste from the cliffs above. At a few points in the rear of the plant of the New England company garnet was recognized as high as 70 feet above the foot of the talus slope. So abundant is the garnet at various points along the base of the cliff that the rock assumes a marked reddish color, and thus, at first sight, might be regarded as quite distinct from the normal amphibolite. From this point upward the garnet gradually disappears. Above the 70-foot mark (barometric determination) it could not be detected in any of the hand specimens with the unaided eye. The microscope, however, reveals the fact that garnet does occur in small amount above this height. The main mass is nevertheless confined to the base of the amphibolite, and probably represents a local contact phenomenon. Its extent, so far as known, is indicated on the map of the Belvidere region.

The texture of the normal amphibolite is quite variable. At the top of the ridge it is a fine grained mass, with occasional bands of feldspathic

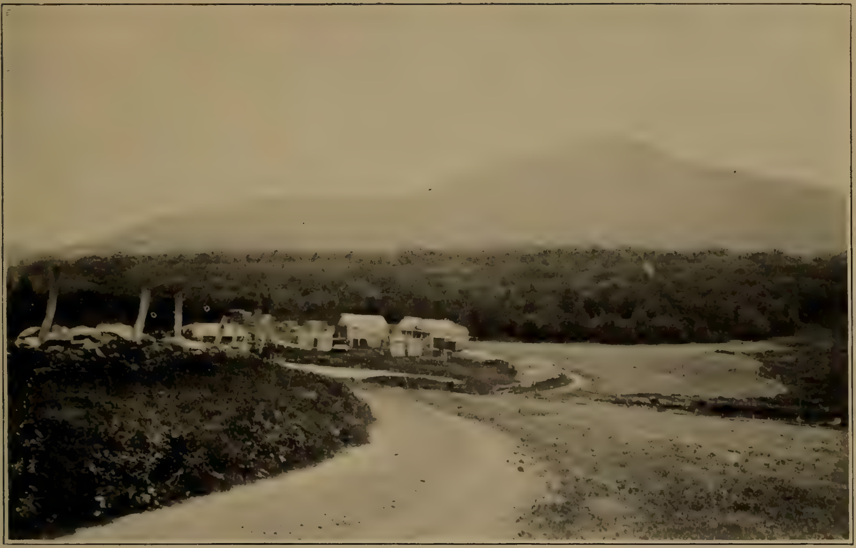

FIGURE 1.—BELVIDERE MOUNTAIN FROM THE NORTHEAST

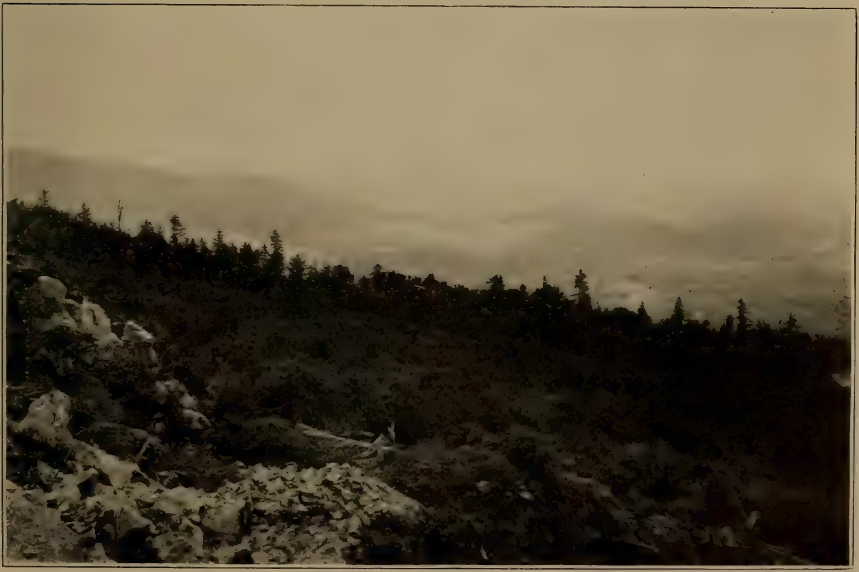

FIGURE 2.—MISSISQUOI VALLEY LOOKING EAST FROM HIGHER SLOPES OF BELVIDERE MOUNTAIN

BELVIDERE MOUNTAIN AND MISSISQUOI VALLEY

minerals and a tendency to split in planes parallel to the minute mineral constituents, 90 per cent of which is hornblende. Half way down the slopes on either side of the highest point the rock assumes a finely fibrous texture. This seems to be a local condition, and does not extend through any great thickness in the central portion of the formation. Again, along the fault on the southwest side of the mountain the amphibolite takes on a fibrous and, at times, a lamellar structure. This also is quite local, it being induced by the crushing and shearing consequent on the faulting. The main body of the formation is moderately coarse in grain, showing cleavage planes 6 or 7 millimeters in length and 3 or 4 in width. It is not uncommon to find in cross-sections of individual hornblende crystals a marked bending or curvature, best shown in sections along the longer axis. The cleavage conforms very closely to one direction, so that the rock splits very easily into plates with an apparent schistose structure. Both pyrite and magnetite grains have been detected with the unaided eye, but in most cases they are in very small amount.

The remaining exposures of amphibolite do not differ in any respect from the typical representative of the coarse grained type, already described. In both exposures there is clear evidence of marked crushing and shearing, particularly in the exposure on the brook as shown on the map. Unfortunately these areas are very largely covered beneath gravel and waste from the slopes, so that it is impossible to determine the extent and relationship of these two small but important exposures. The details of the contact of the amphibolite with the serpentine, as shown in the Tucker quarry to the north of the brook section, will be discussed later. It is sufficient to state here that this contact is believed to furnish sufficiently clear and unmistakable proof of the intrusive origin of the rock from which the serpentine has been derived.

SERPENTINE

Macroscopic characters and mineralogy.—The serpentine is remarkably uniform in texture throughout the entire area. It is rather fine grained, grayish green to dark oily green in color and splintery or hackly in fracture. On freshly broken surfaces it is not uncommon to discern a tendency to assume a lamellar or more often a fibrous texture. The fibrous tendency is invariably associated with zones of shearing and possible thrust. In the upper part of the serpentine belt this texture is most evident along a zone passing through the open cuts of the New England Mining Company. When examined under a hand glass it will be seen that much of the fibrous content of the rock is in reality confined to minute seams and shearing planes and stretched out along the line of movement. It would thus seem that the fibrous content, inasmuch as it fills cracks and seams, even of microscopic size, must be secondary in origin. The stretching of the so-called fiber is due to subsequent slipping after the deposition of the mineral within the original fracture. The same conditions obtain at various points. It is very well shown in the prospects of the United States company (Blake property) 250 feet below the mill of the New England company, as well as in many of the openings made by Tucker, Stone, and Farington along the lower edge of the serpentine deposit. Occasionally on the fresh fractures minute lamellar structure may be seen. Under the hand lens they appear to be small silvery to light-green scales, but too small for specific determination. On the basis of structure it is reasonable to conclude that these minute individuals may be some form of the lamellar serpentine, to which the name Antigorite has been applied. It is to be regretted that sufficient material is not at hand to determine this point.

In the Tucker prospects, however, considerable variation in color and an appreciable range in texture is noticeable. The color varies from light grayish green to oily dark green, and brilliant dark green when wet. Scattered through the mass are many patches of magnetite, with which is associated a very small amount of chromite. It is in the Tucker quarry that the best showing of cross-fiber in this serpentine area can be seen. The dark bands of serpentine are intimately associated with the fiber-bearing veins. They form the adjacent walls, and vary in width with the size of the vein from one to several inches. When the veins form a minute network the whole mass may assume the dark oil green color and then form large bands and blotches 2 or 3 feet in diameter. This peculiar association, so far as observed, is confined to the prospects of the Tucker property.

Local talc lenses.—The main part of the serpentine deposit is a fine grained light grayish green rock, sometimes exhibiting a tendency to become talcose, and wherever this occurs it is accompanied with a slight schistose structure. In fact, on the line of the cross-section, at a point about 150 feet below the edge of the plateau, a number of talc-bearing lenses may be seen. They contain moderately pure talc in the centers, but grade out into the normal serpentine on either side with loss of the schistose structure. From an economic point of view, they are too small to invite any investigation.

STRUCTURE OF THE REGION

The structure of the region is indicated in the accompanying cross-section. Amphibolites form the upper 1,000 feet of Belvidere, and include the steep slopes extending upward from the crescent-shaped plateau, the latter being composed of serpentine. At the juncture of the two rock types is a band of garnetiferous amphibolite. An important fault occurs on the west side of Belvidere. This was first recognized by Professor J. F. Kemp. How extensive the faulting may be was not determined. It is to be said, however, that certain features in the topography of the western slopes suggest that series of faults may occur to the north and may have been a determinative factor in the minuter topography of this unique and picturesque ridge. On the eastern slopes no faults were detected. Much local crushing and local shearing is evident within the limits of the serpentine. Such shear zones are intimately associated with the so-called asbestos. On the Tucker property, at the foot of the plateau, are to be found certain structural facts which at first suggested the occurrence of a zone of crushing and shearing. At this point a contact between the serpentine and amphibolite is unmistakably clear. This was at first regarded, on the basis of a field observation, as a fault, the crushed zone of serpentine forming a very favorable depository for the cross-fiber. It will be shown, however, that the contact of the serpentine with the amphibolite does not represent a fault plane, but an igneous contact. The development of a crushed zone adjacent to the contact is necessarily a subsequent phenomenon. The remaining instance of a possible contact relationship is to be found a few hundred yards to the south of the preceding case. Its location is shown on the accompanying map. Here crushed amphibolite was found within a few feet of the serpentine. Whether, as in the preceding case, an igneous contact or a simple fault zone may exist here could not be determined with any degree of certainty, but it is believed the former is the case. Unfortunately the greater part of the rim or foot of the plateau is buried beneath a coat of waste and till, which renders further discovery of structural relationships well-nigh impossible.

Protruding through the till may be seen excellent exposures of the surrounding schists, which form the valley floors and subordinate ridges in the immediate vicinity. It maintains a very steep dip, with a strike varying from nearly true north to north 20 degrees east. A considerable variation in the lithologic characteristics of the schists obtain. The variation may be marked in a comparatively short cross-section. Bands of micaceous rock, which at times are apparently talcose to a slight degree, are followed by sandy schists, including small lenses of quartz, with an appreciable amount of pyrite. No limestones were found in the vicinity of Belvidere. The positions of a few of the outcrops noted are indicated on the map. The structural features, in conjunction with the mineralogy of this formation, favor the view that at least a large part of this terrane is sedimentary in origin.

Early Knowledge of Asbestos and Its Uses

It is a well known fact that the early Greeks and Romans were acquainted with the economic uses of asbestos fiber. The idea of an organic origin has been attributed to Herodotus, who considered it "a kind of mineral wool" which grew on trees. According to the same writer, cremation cloth was made of this material, it being used to completely cover the body, hold and keep separate the remains from the fuel used in the funeral pyre. Pliny also speaks of it as a rare and costly cloth, the funeral cloth of kings. Assuming its vegetable origin, he calls it "linum vivum," the difficulty of weaving which, he says, was very great on account of the shortness of the fiber, which is a somewhat singular reason to give, seeing that he was not speaking of chrysotile, to which the remark might with some justice have been applied, but to the Italian mineral amianthus.*

It is known that asbestos was made use of in connection with the sacred fires in the temples of the gods. It is also stated by some writers that this material was employed in the preparation of wicks for the lamps of the Vestal virgins. Strabo and Plutarch both speak of these lamps, calling them *ἄσβεστα* (perpetual), because the wicks maintained a perpetual flame without being consumed.† Asbestos cloth was probably used as well for the preparation of napkins and certain forms of dress. It was not, however, until the beginning of the last century that the application of this mineral product began to be recognized in the mechanical arts. Moreover, its uses as known in the olden times may still be seen in Greenland and Labrador, where the natives are known to twist it into lampwicks.

While it is more than probable that asbestos paper and cloth were manufactured as early as 1700, in Norway the modern history of asbestos as a useful commodity dates from the beginning of the last century. Early in this period we find Madame Perpenti of Cone engaged not only in the manufacture of paper, but also cloth from an Italian product. Its first use as a means of protection to firemen is attributed to Chevalier Aldini, 1850, and a little later we find one Guiseppe della Corona, a cultured Florentine priest, engaged in the manufacture of millboard; and, later still, Signor Albonico, having given some attention to this product of the mountains of his native province, joined himself with a priest, Corona, and the Marquis di Baviero, a distinguished Roman nobleman, in the manufacture not only of asbestos cloth, but asbestos paper as well. Having to some extent succeeded in this, they were unsuccessful in their endeavors to secure a contract with the Italian government for the supply of paper for the use of bank notes and other securities, any prospects they might have had in other directions being effectually destroyed by the outbreak of the Franco-German war of 1870.

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* Jagnaux, Traité de Min.; also Quenstedt.

† Quenstedt, Handb. der Min.

Development of Canadian Industry (Thetford)

In this country and Canada chrysotile was not known to exist in any quantity until the seventies. It was discovered in Canada long before this date, for in 1862 specimens of Canadian chrysotile were exhibited at the International Exhibition in London, England. It was then regarded as a mineralogical freak rather than a product of great economic importance. In a report of the Canadian Survey for 1847–1848 reference is made to its occurrence in serpentine rock in the region of Bolton. But, while the extension of the belt of serpentine rocks in which this mineral is known to occur had been traced with some care from the Vermont boundary in the township of Potton to and beyond the Chaudiere river, the deposits of asbestos observed were comparatively limited. In the United States veins generally of short and harsh fiber were found at several points, and a considerable quantity of a tremolitic variety was mined, which, while ill adapted for the purpose to which asbestos is now generally applied, was used for the manufacture of fireproof paints, cements, etcetera. The chief source of supply for fibrous asbestos was the mines of Italy, where deposits of irregular extent occur, the mineral often possessing a long and silky fiber, which well adapted it to spinning, and from this source the material for fireproof curtains and similar manufactures were obtained. In 1877–1878 asbestos was discovered in the serpentine hills of Thetford and Coleraine. The size of the veins, often several inches thick, led to the expectation that deposits of value might exist there, though their true importance was not ascertained for several years. The credit of the discovery in this locality is claimed by Mr Robert Ward, though by others it is stated that the first find was made by a Frenchman named Fecteau. Following closely upon the discovery several parties secured areas both at Thetford and Black Lake, in Coleraine township, on the line of the Quebec Central railway, which for some miles runs . . . between high ridges of serpentine, in which, the timber having been burned off, the veins were observed at the surface by the weathering and felting of the mineral on the surface of the bare rock. From this time (1878) on the industry developed with the demand for the product. Early in the nineties the region became the leading producer of the world, and holds that position at the present time. In

1903 the United States produced but 2.4 per cent of the value of the imported product. This condition should stimulate the most strenuous search for so valuable a product.

GEOLOGY OF THE CANADIAN AREA

Concerning the lithology of the Canadian area, Mr Ells says:

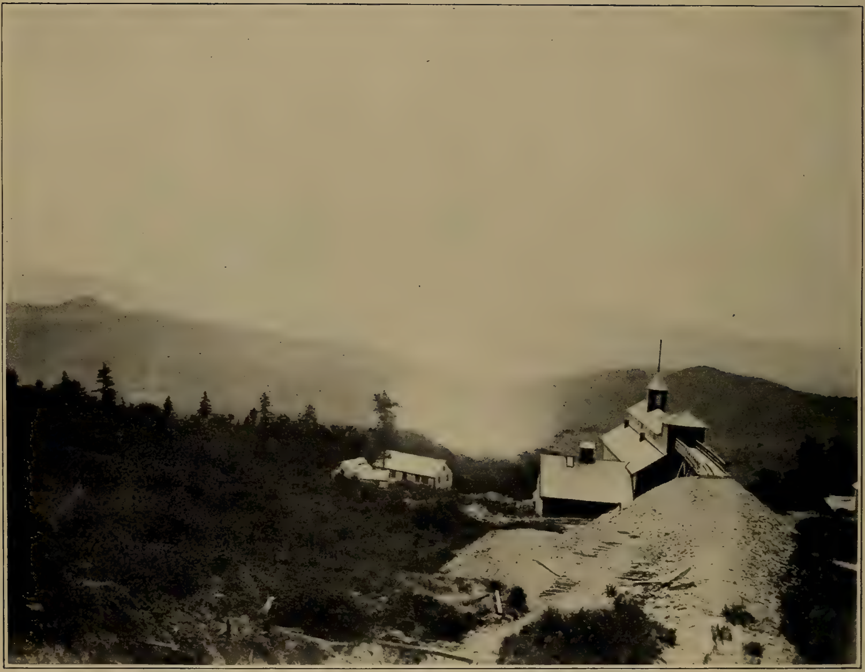
> "All the mining locations are situated on areas of serpentine, which is associated with green, gray, black, or reddish slates and quartzose sandstones and conglomerates. The serpentine is more particularly related to considerable masses of diorite and whitish granitic rock, and is apparently due to the alteration of portions of these masses. . . . These slates and associated rocks are supposed to belong to the Cambrian system, though the serpentine is sometimes connected with areas of older rocks, such as chloritic and talcose schists and considerable masses of soapstone. In the serpentines which are found with the older rocks the asbestos appears to be in very limited quantity, and no attempt has been made to work any such deposit."

North of the Saint Lawrence river, in Ottawa county, are a series of serpentinous limestones, of probable Laurentian age, which contain a small amount of fiber, but its grade is too low to be of any considerable value as compared with the products from the Thetford region. Serpentine areas are known, too, to exist in a line extending to the northeast in the direction of the Gaspé peninsula, but little is yet known about these occurrences as possible producers in the near future.

VERMONT ASBESTOS

OCCURRENCE

The discovery of asbestos in this region is to be accredited to Judge M. E. Tucker, of Hardwick, Vermont. On November 9, 1899, he recognized the possibility of its occurrence in sufficient quantities to warrant careful prospecting. A considerable area lying along the township line between Lowell and Eden, as well as a portion of the belt passing through Lowell village to the north, was examined with considerable care. At a later date portions of the Lowell area were investigated by Mr Silsbey, of Lowell. During the two succeeding years the Belvidere area attracted the attention of some of the more prominent miners of asbestos in the United States and Canada. In 1900 Mr B. B. Blake likewise discovered fiber in the ledges on the southeast slopes of Belvidere, in Eden township. These finds at once increased local interest, and later led to the formation of a number of companies, but only one proceeded beyond the prospecting stage. In 1901 the New England Asbestos Mining and Milling Company erected an elaborate plant, equipped with the most



VALLEY AT FOOT OF BELVIDERE MOUNTAIN, LOOKING SOUTHEAST

Showing plant of New England Company

modern machinery for the treatment of asbestos-bearing rock. Active mining operations were begun in May, 1902, but in October of the same year the plant closed its doors. No official statement has been obtained concerning the amount or the grade of the fiber produced or its value in the markets at that time. That seen by the writer, which was said to have been the product of the New England mines, while too short for purposes requiring tensile strength, should fill the standard requirements in the manufacture of all asbestos goods in which non-conductivity of heat is the only essential quality desired. A view of the New England plant is shown in plate 74.

KINDS—SLIP-FIBER AND CROSS-FIBER

While it is universally true that chrysotile is confined to serpentine, it is by no means true that all serpentine deposits contain it. Although the Belvidere area is a difficult one to investigate as regards structural details, sufficient data have been obtained to demonstrate with reasonable certainty that the fiber contents are very largely restricted to certain belts, the localization of which is due to structural features confined to the serpentine deposits. In the open cuts and prospects made, especially by the New England Asbestos Mining and Milling Company and others near the upper contact with the amphibolite, the fiber, when in sufficient quantity to be easily detected, shows that it is largely confined to a shattered and sheared zone of rather limited extent. In the central part of the zone are large masses with slickensided surfaces. Wherever cross-sections of these could be found careful examination revealed the fact that they in turn were also sheared, and could with a little careful manipulation be separated into a series of smaller wedge-shaped masses, each with smoothed surfaces. It is along these planes that the fiber has attained its maximum development. It occurs in two forms, and has been so recognized by the local prospectors. In a large part of the zone of shearing the fiber has stretched or pulled out along the slipping planes, and hence has been called "slip-fiber." In certain parts of the area, however, there has been a maximum development of fracture with minimum shearing. In such fractures the fiber has assumed a transverse position, and is locally known as "cross-fiber." The same phenomena may be seen in thin-sections prepared from smaller blocks.

With regard, therefore, to the structural details bearing on the areal distribution of the fiber the facts as they now appear force the conclusion that the fiber will be limited to the zones of fracture and shearing. How many of these exist within the serpentine zone under consideration is a difficult matter to determine. Enough data are available, however, to indicate that a zone of fracture with marked shearing crosses the property of the New England company. It is probable, too, that a smaller one crosses the property of the National company. A third belt of fracture with minimum shearing occurs on the property of Judge Tucker. This case is adjacent to the igneous contact to be discussed in another section. The fiber is largely of the "cross-fiber" type. It has the color and luster of true chrysotile. Under the blowpipe it behaves in all respects like the fibrous form of chrysotile. It yields considerable water and is nearly infusible. There is a tendency on continuous application of the flame for very fine films or strands of the fiber to become noticeably brittle. The cross-fiber was, however, quite uniform in its behavior before the blowpipe. Still one or two samples did not yield as much water as should be expected in true chrysotile. How prevalent this may be has not been determined.

The "slip-fiber" differs from the "cross-fiber" in having a duller and waxy luster, less flexibility, and a tendency to develop a coarser but longer strand, sometimes reaching 3 inches in length, while the latter rarely attains 1 inch in length. Under blowpipe tests the slip-fiber yields much less water and fuses, with some difficulty, to a white enamel. The color test for calcium was also evident. These reactions strongly suggest that the slip-fiber is not true chrysotile, but a fibrous form of amphibole. This variety, however, is on the market as asbestos, but its market values are much less and its uses not so great in range.

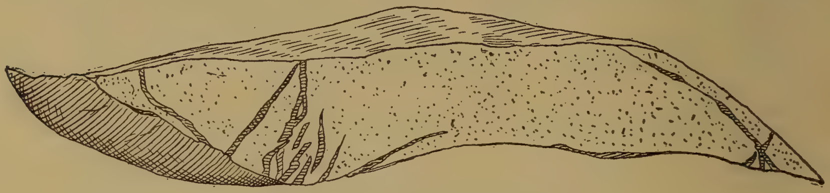


FIGURE 3.—*Cross-section of a Slip-block.*

Showing the minute fiber veins in a position where the block would be subjected to the greatest strain, and hence offer the best lines along which the fiber might develop.

At the lower contact of the serpentine with the amphibolite on the Tucker property is the best showing of cross-fiber seen in the entire belt. It is only just to say, however, that it does occur as well on the land of the New England company, but in very small amount. While cross-fiber is the more prominent of the two sorts, shearing, which seems to be a constant associate with the slip-fiber, is by no means absent in the Tucker exposures. It is confined, however, to very narrow zones. On the other hand, the cross-fiber is very largely confined to the borders of the thrust zone, and, so far as could be seen from the new exposures,

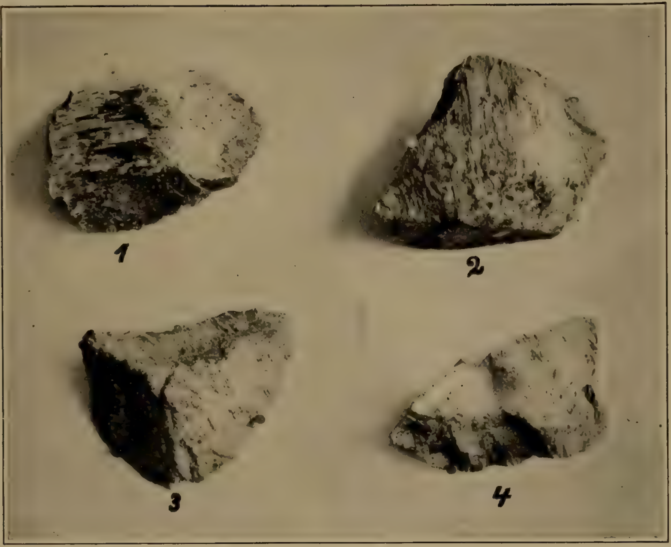


Figure 1.—Slip-blocks from the Tucker Property

Showing rounded character of edges on flatter sides and film of fiber on surface

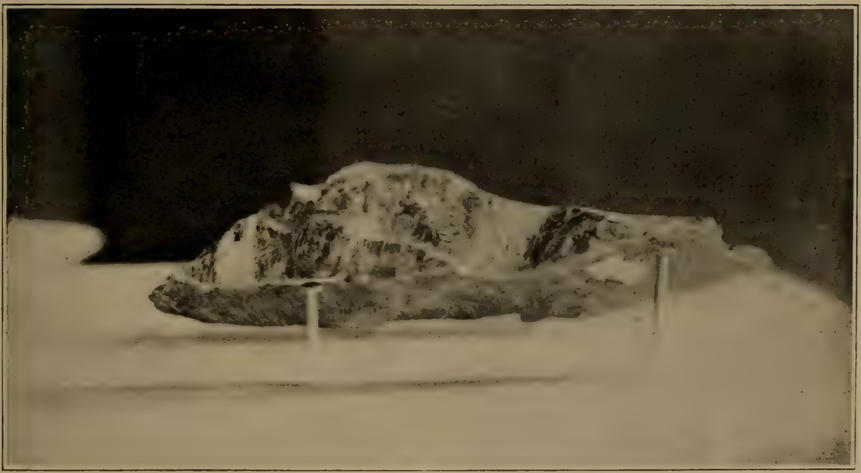


Figure 2.—Side View of Block Number 4

Showing sharp edge of the slip-block and the slicken-sided and film-covered surface

SLIP-BLOCKS FROM THE TUCKER PROPERTY

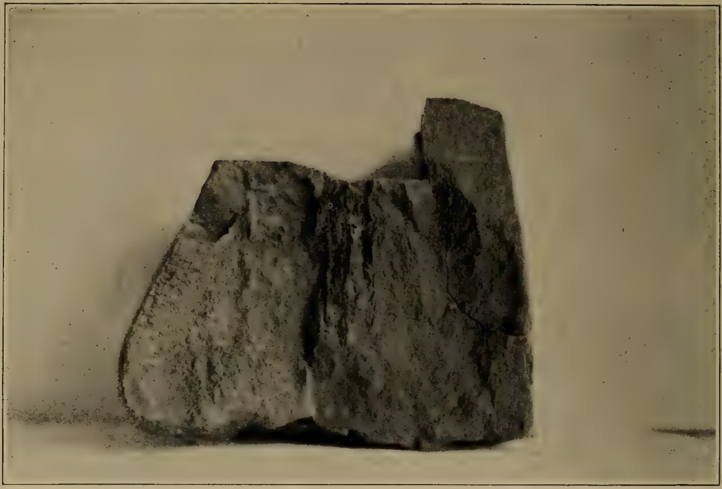


FIGURE 1.—BLOCK FROM THE SERPENTINE-AMPHIBOLITE CONTACT ON THE TUCKER PROPERTY

Light colored or left-hand side of the block is serpentine; dark portion amphibolite. Sharpness of line of contact best shown at upper and lower edges

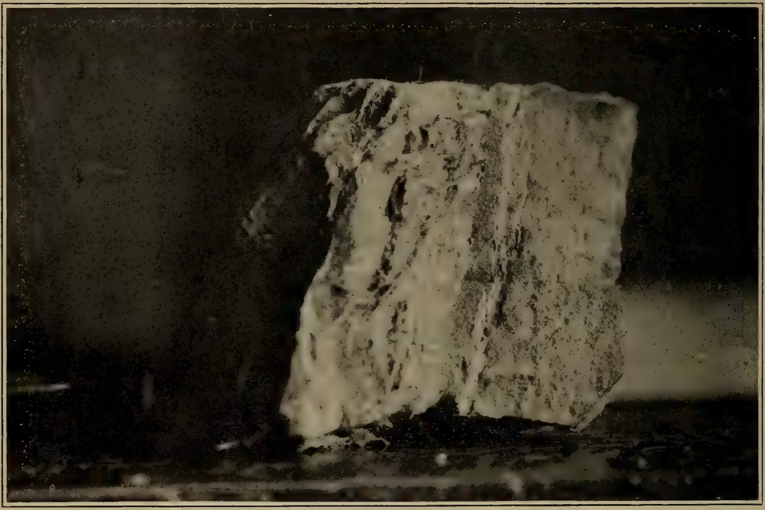


FIGURE 2.—SECTION OF CROSS-FIBER VEIN

Fiber at intervals is separated by films and bands of magnetite. Ore-bands may be central or lateral, but are rarely well developed adjacent to the serpentine. They sometimes fill what appears to be a fractured wall or edge of the fiber-band, which in some respects suggests a replacement of the serpentine by the fiber along a line of weakness, and not necessarily the filling of an actual crevice in the rock.

SERPENTINE BLOCK AND A SECTION OF A CROSS-FIBER VEIN occupied a greater breadth or area than the zone of thrust. Nowhere in the field are small slip-blocks better developed than at the Tucker contact. The accompanying illustration (plate 75, figure 1) gives some idea of the form and character of the surface. It will be seen that the surface has been polished and sometimes covered with a fibrous film of hornblende, which has been stretched or pulled out in the direction of movement. In consequence of the shearing the trituration of the blocks upon each other has produced alternate sharp angles around the greatest periphery, with alternating obtuse edges roughly in a plane at right angles to the plane of the former and along its greatest diameter, or as many as three obtuse angles may occur on each flat surface of the block. In cross-section minute partings may be seen lying roughly parallel to the trend of the surfaces and filled with glistening films of fiber—that is to say, the strain to which these masses were subjected was so great that they in turn were also fractured and subsequently knitted together by the deposition of silky fiber. These facts are shown in the sketch (figure 3) of the cross-section of one of these blocks.

STRUCTURE OF CROSS-FIBER VEINS

A cursory examination of any block containing typical cross-fiber veins shows that they usually occur in groups of bifurcating and rejoining members, usually associated with one or two larger members not exceeding 1 inch in diameter. This feature is shown in the following sketch.

In thin-section of even the microscopic veins magnetite and probably a small amount of chromite are found to be constant associates. Pyrite was also recognized, but in very small amount. In the hand specimen it would appear that the magnetite was confined very largely to the central portion of the individual vein. In thin-sections of the smaller veins this relationship is not so evident. On the contrary, sections may be selected in which there seems to be no localization of the metallic contents, which are scattered throughout the entire width of the fiber band and extend well into the body of the serpentine. This, however, is not the rule, but rather the exception. From the material at hand I think we may safely conclude that the ores have a decided tendency to accumulate within the central zone of the fractures, while the deposition of the fiber favors the walls.

DISCUSSION OF PROBABLE MODES OF GROWTH

The method of growth of the fiber and its relation to the ores is a vexed problem. Whether its deposition begins on the walls and gradually pushes its growth toward the central space and finally coalesces along a central line or whether the fiber develops simultaneously along its entire length is not easily demonstrated. If the latter were true and the deposition of the ores were cotemporaneous with the growth of the fiber we should not expect to find a tendency toward central localization of the metallic contents, for the chances for uniform deposition at all points within the crevice would be equally good. It is true that such conditions can be found, but do not conform to the general plan observed.

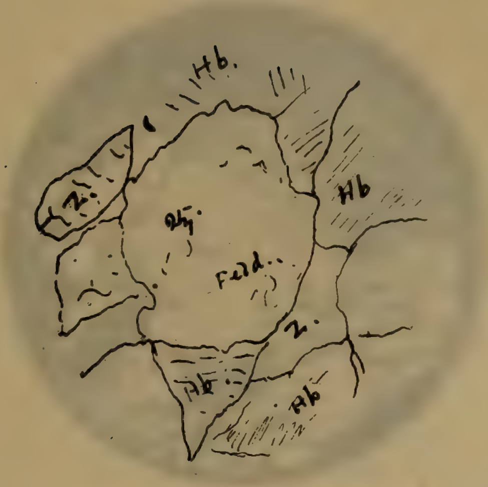
On the basis of the first hypothesis, if we assume that the fiber began its growth on the walls of the fracture and pushed its way toward the center, then we should expect an increasing amount of ore deposition in the central portion, with the infringement of the fiber from the sides. As a matter of fact the ore does, in the majority of cases seen, favor a central position, as if the circulating waters which carried the ore were compelled to move in a central zone. It follows, then, as a consequence of this sort of growth that a coalition and knitting together of the opposing ends as they came in touch should result. Moreover, it would seem that the line of juncture should be detected in cross thin-sections, for it would be most remarkable that the growth of opposite individuals or strands should have the same optical orientation and unite in such a way, where not interfered with by the deposition of iron ore, as to appear to be one and the same individual. In the few sections at hand I have not been able to detect this relationship, but it is believed that further study of the problem may show that this interpretation is in the main the correct one.

It might be said that the deposition of the ores was subsequent to the growth of fiber and along secondary fractures within the body of the latter. It is true that the fiber-bearing veins have been sheared, for it is this process that has produced the slip-fiber. This supposition may be true, but it still remains that veins which do not show any evidence of shearing or fracture also contain much magnetite in central partings or as rods and bunches parallel the strands; hence in such cases there was no opportunity for the subsequent deposition of the ore. While it must be admitted that sufficient material and data are not at hand to solve the problem, it is believed that such facts as we have favor the interpretation as expressed in the above hypothesis.

Amphibolite

MICRO-STRUCTURE AND MINERALOGY

In the predominant type of amphibolite hornblende is far in excess of all the other constituents combined. It makes up from 70 to 90 per cent of the entire mass. In thin-section the hornblende appears as large in-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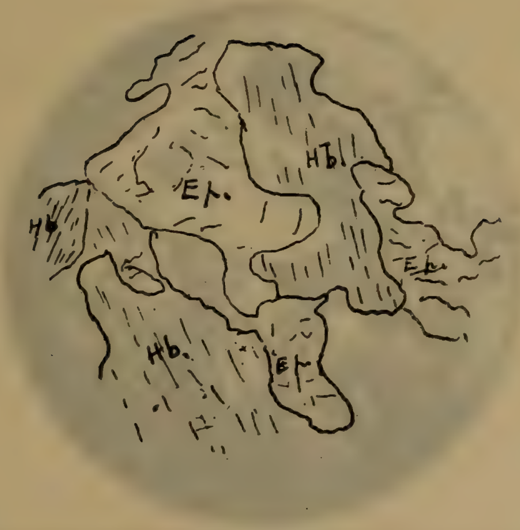
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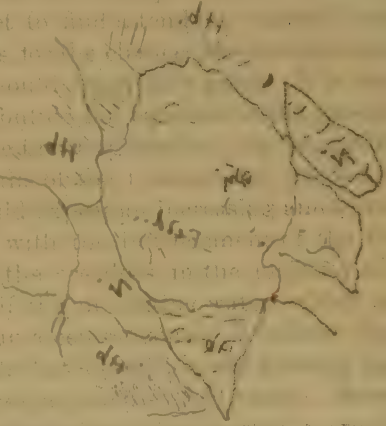
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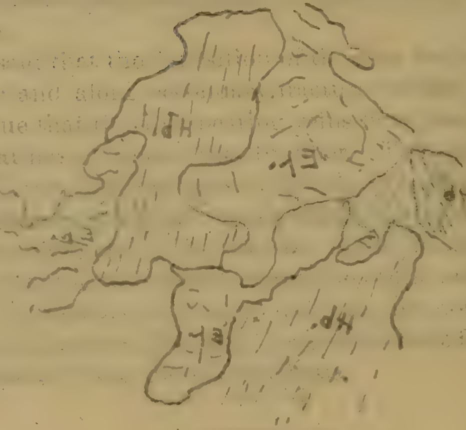
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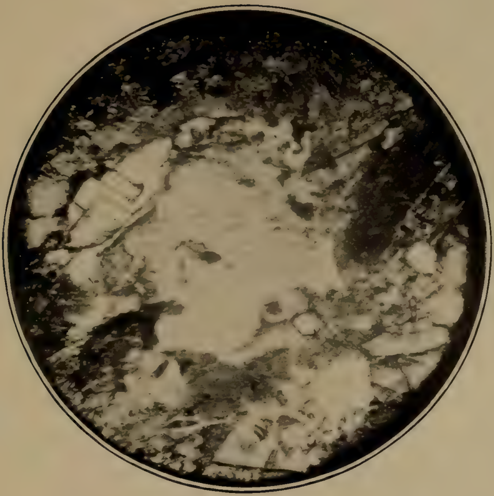

FIGURE 1.—SECTION (46) OF AMPHIBOLITE

Showing central mass of secondary quartz and feldspar with secondary zoisite and hornblende

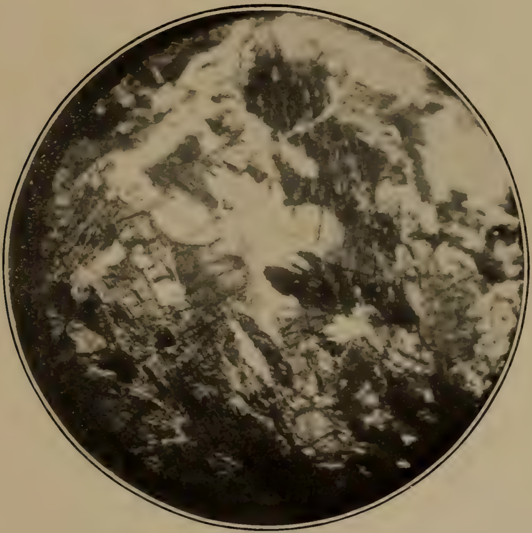

FIGURE 2.—TYPICAL AMPHIBOLITE (SECTION 58*a*) WITH SMALL AMOUNT OF EPIDOTE

PHOTOMICROGRAPHS OF AMPHIBOLITE

dividuals, roughly columnar in outline and from 5 to 8 millimeters in length. They are sometimes intimately interlaced or grouped in bundles. Judging from the cleavage surfaces as seen in the hand specimen, one is surprised that the cleavage partings are not more prominent in the thin-section. In sections normal to the vertical axis the cleavage partings are well defined, but in the prismatic and pinacoidal zones, while in instances easily recognized minute hair-like lines, often fading out and reappearing again, may still be so fine that a higher power is necessary to make this structure clear and evident. There is also a rude transverse parting, which in the main should correspond in direction and position to the plane of the basal pinacoid (001). The pleochroism is unusually strong. It ranges from a greenish yellow parallel 𝔞 to bright green on 𝔟 and blue on 𝔠. This is a characteristic feature of the hornblende in amphibolitic schists.

Not infrequently the hornblende shows evidence of decomposition and passage into secondary products. In most cases the decomposition product is ordinary chlorite, but transitions into penninite are not uncommon. It can be recognized by its deep purple interference color, which does not appear in any other member of the chlorite group. In its passage to chlorite the typical cleavage of the original is lost and a scaly or lamellar structure occurs. Very minute inclusions may be also recognized. They lie in two positions—either parallel the prismatic cleavage or normal to it. Occasionally larger individuals may be indiscriminately scattered through their host.

In addition to the hornblende there occurs a variable percentage of a light colored to colorless silicates. A large portion of these constituents is orthorhombic epidote or zoisite. The lack of extinction angle and prevalence of low interference colors, not exceeding those of the first order, serve to distinguish it from monoclinic epidote, which exhibits an extinction angle and interference colors approaching the third order. In most sections the greater part of the colorless silicate is zoisite. Two cleavages are prominent, one lying parallel to the long axis (c), the other a prominent transverse parting at right angles to the former and sometimes fading out before traversing the entire width of the individual. Inclusions are present, but no systematic arrangement is prominent. They are usually too small to make specific determination with any degree of certainty. In a few cases, however, it is comparatively easy. The peculiar pink tint and rhombic outline of faces as may be seen under a high power (240) show that some of these inclusions, at least, are minute garnets. They are confined to the central portion of the host. On account of the predominance of the optical properties of the host the isotropic character of the garnet is completely overshadowed. In addition to them are many rod-like and acicular inclusions, the identification of which, however, is not an easy matter.

The remaining light colored silicate is epidote. It may occur as grains, produced in part by crushing, or in rudely columnar masses with ragged ends and irregular sides, the individuals sometimes attaining a length of 4 or 5 millimeters. The maximum extinction angle observed was 11 degrees.

Two cleavages are present, one parallel to the long axis and poorly developed, the other a transverse parting clearly exhibited on account of the rather strong refraction so characteristic of this mineral.

Very little pleochroism is recognizable. In most cases it is colorless, but occasionally a slight tinge of yellow is apparent.

Very minute inclusions are arranged parallel to the long axis, but are quite too small for specific determination. Magnetite is an omnipresent accessory, or probably a secondary product resulting from the decomposition of some of the essential components. There are also present small wedge-shaped or irregular grains, which behave in all respects like titanite.

LOCAL VARIATIONS

Garnet zone.—There are certain local variations in the mineralogy of the amphibolite which should be noted at this point. The exact geographical distribution of this feature has not been worked out in the fullest detail, but so far as can be determined from the field observations and collections at hand the greatest deviation from the normal type occurs along the line of contact with the serpentine, best seen back of the plant of the New England company and again along the fault on the west side of the mountain, the position of which is indicated on the geological as well as the traverse map. The former is a zone of variable width, lying at the base of the amphibolite cliffs and characterized by the development of a very large amount of garnet, easily detected by the unaided eye, and in patches so abundant as to give the rock a reddish hue. In thin-sections various stages of alteration to chlorite are evident. The well developed crystalline outline so characteristic of fresh and unaltered garnet is largely destroyed. Such fresh grains of the individual as may remain are usually surrounded by rims of green to yellowish-green chlorite. With it are associated small amounts of secondary quartz and feldspar, which permeate the cracks of the original garnet and also form rims at the periphery of the individual. Indeed, the alteration may be so complete that no trace of the original garnet is evident, and there remains only the general outline. In such cases the central portions are chiefly composed of chlorite, while the outer portions

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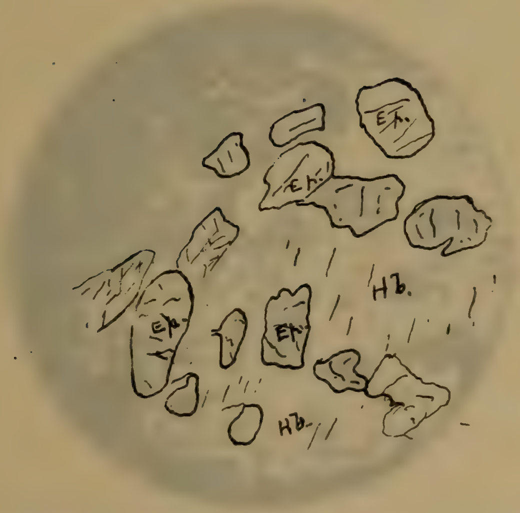
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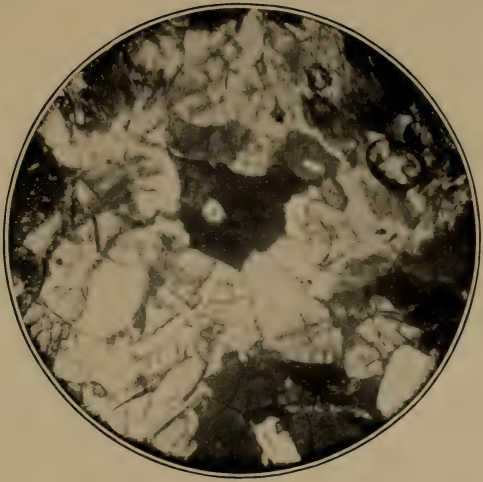

FIGURE 1.—SECTION (87) OF TYPICAL AMPHIBOLITE FROM THE LOWER CONTACT ON THE TUCKER PROPERTY

Section shows crushed epidote in a mass of partly altered hornblende

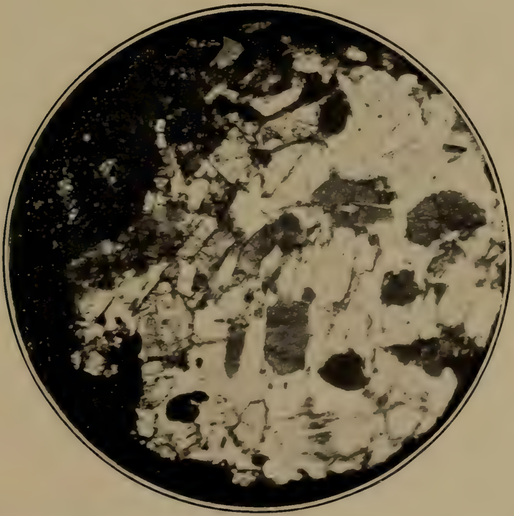

FIGURE 2.—AMPHIBOLITE (SECTION 45) CONTAINING LARGE AMOUNT OF GRANULATED EPIDOTE EMBEDDED IN CRUSHED HORNBLENDE

PHOTOMICROGRAPHS OF AMPHIBOLITE

are occupied by the quartz and feldspar. In nearly all cases the chlorite belongs to the variety penninite. It should be added that garnet is not confined to the zone indicated on the map. Several sections from points well up the western slope, as well as near the top on the eastern side, show garnet changed to penninite. The amount is very small and probably local in development.

Development of anthophyllite.—Along the fault line already referred to there are some modifications of the normal amphibolite worthy of detailed study. While the fault is sharply defined—about midway of the line as indicated on the map—it can nevertheless be traced a short distance above and below by a breccia zone. The amphibolite along this zone has taken on a schistose and somewhat fibrous texture. The original hornblende has been crushed and granulated to such an extent that the primary structure has been largely obliterated and the mass now in part altered to chlorite. Embedded in the chloritic mass are numerous fibrous individuals, with ragged terminations and fairly well defined prismatic boundaries. No pleochroism is evident. A transverse and longitudinal cleavage is easily detected. The former is the more prominent of the two. The relief is quite strong, and hence the interference colors are correspondingly high. The lack of extinction angle, the high interference, and absence of pleochroism places this mineral with the orthorhombic amphiboles. It is regarded as anthophyllite. The section (45) containing this mineral was found in line with the extension of the fault. Its position is shown on the traverse map. Embedded in the rock are also many grains of garnet, now altered to penninite. It is not improbable that the garnetiferous zone may extend to and beyond this point, and that the anthophyllite is consequent upon the shearing, and hence entirely local in distribution.

The remaining amphibolite localities occur at the Tucker quarry and again on the little brook a few hundred yards to the south (see map, figure 1). In both cases the rock belongs to the normal type. In the latter, however, there is abundant evidence of crushing, thus suggesting that a sheared zone or line of faulting might be near at hand. No clean contact could be found. Typical serpentine occurs within a few feet of the amphibolite exposure, but owing to the density of the forest and the heavy covering of loose materials the interval between these two points could not be seen.

SERPENTINE

CRITERIA FOR DETERMINING ORIGIN

In the previous investigations of serpentine and its probable origin it has been found that by far the greater number of cases on record are regarded as having been derived from some form of basic eruptive. The interpretation rests on the possible preservation and recognition of remnants of mineral constituents belonging to the original mass, or in cases of complete alteration, at least, the retention of some of the characteristic and determinative structures belonging to the essential minerals of the original rock.

MICRO-STRUCTURE OF BELVIDERE SERPENTINE

Types.—On the above basis the following types of structure have been established as proof of the kind of rock from which the serpentine was derived:

(1) *Mesh structure,* in serpentine derived from olivine.

(2) *Bastite structure,* in serpentine derived from enstatite or bronzite.

(3) *Lattice structure,* in serpentine derived from non-aluminous hornblende.

(4) *Knitted structure,* in serpentine derived from non-aluminous augite.

In the Belvidere serpentine, however, serpentization is so far advanced that the recognition of original structures belonging to minerals of the original rock is rendered well-nigh impossible in the majority of cases. There are, however, a few sections which shed some light on this most interesting question.

In sections of the normal and fine grained serpentine two distinct types of micro-structure can be seen—one, a very complete fibration of the rock, the other assuming a noticeable lamellar phase or possibly scaly habit. If structure alone is the only essential element necessary upon which to recognize and classify serpentines, the latter should be regarded as lamellar or antigorite serpentine.

Fibrous serpentine.—In the fibrous group at least two distinct arrangements of the fibers may be seen, with all gradations between; in one the fibers are arranged in parallel series and in bundles; in the other they show a marked tendency to diverge at the ends or to radiate from centers, and sometimes even to interlace. More than one phase may appear in a single section. According to the interpretations of A. Lacroix and others, the variations in structure may be and are used as a legitimate basis for the establishment of distinct mineral varieties. If these varietal forms, however, are crystallographically and chemically one and the same thing, it would seem to be undesirable to give specific names because of variation in form alone.

The greater part of the Belvidere area shows a markedly fibrous structure. No particular arrangement is characteristic of any limited part of the area. Coarse and fine textures may be found in the same prospect.

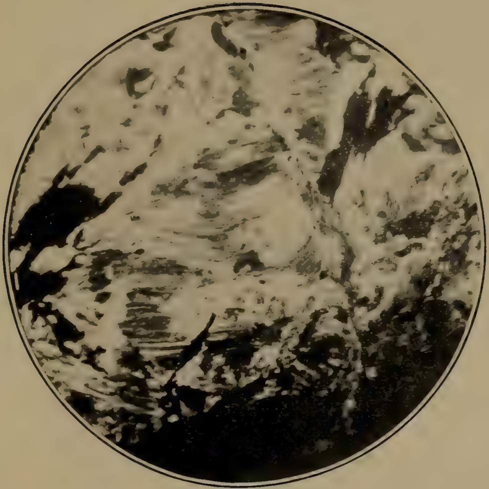

FIGURE 1.—SECTION OF SERPENTINE, U. S COMPANY, PIT NUMBER 3

Showing parallel fibrous structure

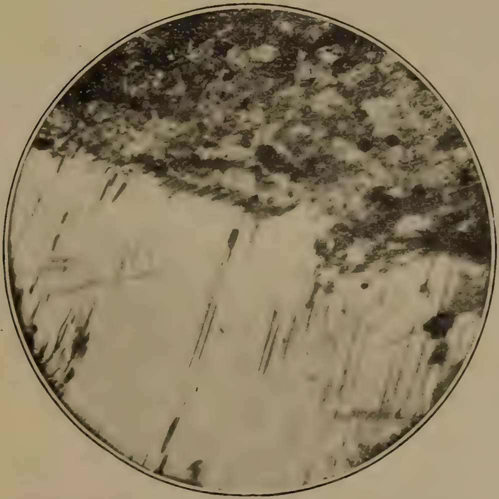

FIGURE 2.—SERPENTINE AND ASBESTOS VEIN (SECTION 90)

Showing the sharp line of contact and a tendency to shearing at the extremity of the fiber band

PHOTOMICROGRAPHS OF SERPENTINE

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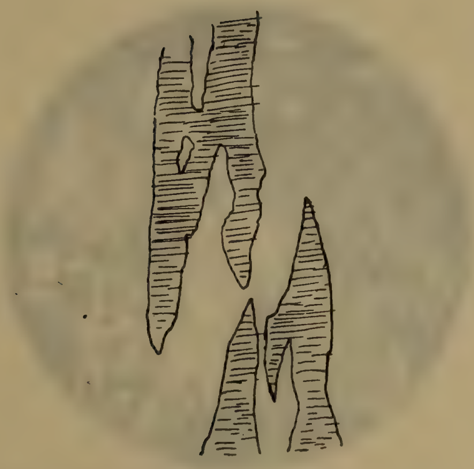


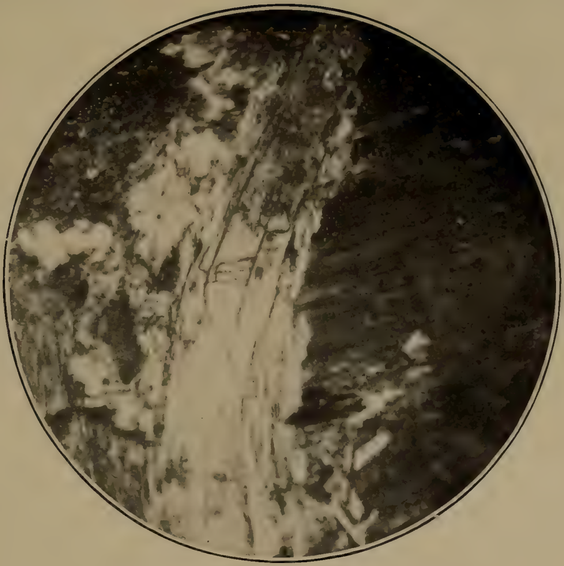


FIGURE 1.—PHOTOMICROGRAPH OF SECTION 89

Showing the cross-fiber and bifurcation of the amphibolite veins. The relation of the parts is such as to strongly suggest fracturing by shear-pressure

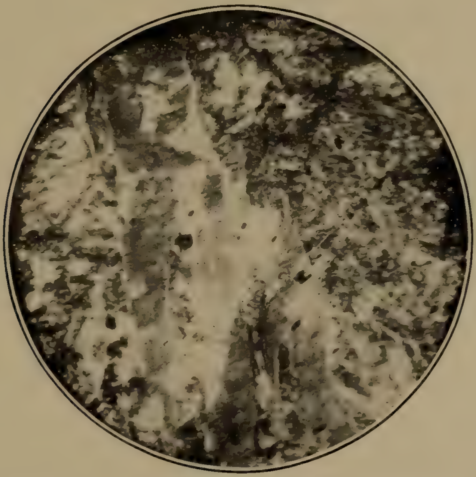
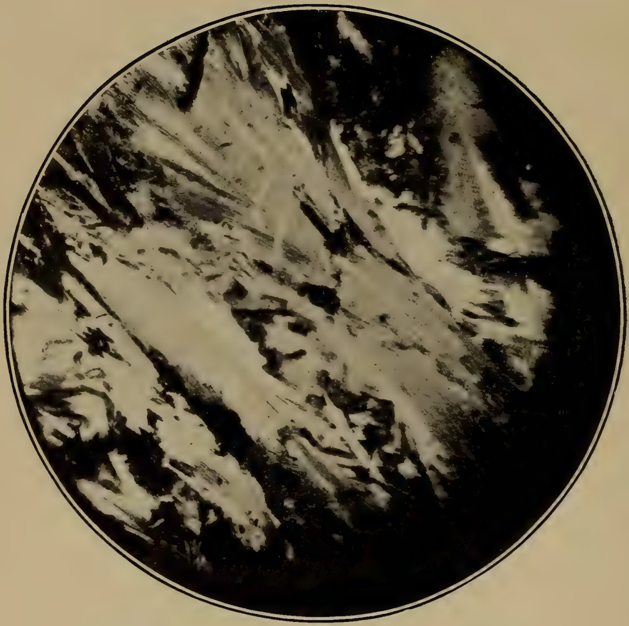


FIGURE 2.—SECTION (40*A*) OF TYPICAL COARSE AMPHIBOLITE

Showing the curved cleavage partings in a large hornblende

PHOTOMICROGRAPHS OF AMPHIBOLITE



PHOTOMICROGRAPH OF SERPENTINE (SECTION 42)

Showing the divergent arrangement of fibrous structure of the serpentine

The parallel and radiate arrangement may be found in the same section. According to Rosenbusch, the parallel arrangement is regarded as the chrysotile variety, while the radiate is characteristic of picrolite and the divergent phase of the metaxite variety. The parallel and divergent structure is fairly well shown in sections numbers 7 and 57, from pit number 2, United States company. Section 42 shows a very good case of the divergent and interlaced arrangement, while the lamellar or antigorite variety is well illustrated in sections 43 and 58.

Lamellar and bastite serpentine.—While most of the sections from the serpentine area show the characteristic fibrous aggregates common to thoroughly serpentinized rock, there are in certain sections some additional features, which are believed to throw some light on the probable origin of the original mass. Some of these features are shown in sections 51 and 69. It is not uncommon to find a series of parallel laminæ making up an individual crystal. In some cases grains or stringers of magnetite may be distributed along the partings. In all cases parallel and perpendicular extinction is obtained. These individuals appear like secondary masses derived from an orthorhombic pyroxene, probably some such mineral as enstatite. In other words, the secondary mass is bastite, a pseudomorphous product which is so common in members of the gabbro family. It would thus seem probable that the original rock from which the serpentine was derived was a massive igneous rock in which an orthorhombic pyroxene formed an essential member (see also section 57).

Discussion as to Origin

CONTACT PHENOMENA

The locality yielding the most important facts bearing upon the probable origin of the rock from which the serpentine was derived is the contact on the Tucker property. The contact is clear and well defined, as shown in the accompanying photograph of a block (plate 76, figure 1), showing both the serpentine and undoubted amphibolite and the marked line between them. As seen in thin-section, it is very clearly defined. Near the line of junction the serpentine is almost isotropic. When examined, however, in parallel polarized light and under a sensitive tint there appear minute fibrous and block-like individuals, which suggest an actual crystalline structure. At the immediate contact the serpentine assumes, under cross-nicols, a deep ultra-blue color. This area includes a part of the absorbed edge of the amphibolite, for the individual components of the amphibolite may be traced by gradations into the blue areas, where they finally lose their optical characteristics. In other words, these facts show that the amphibolite has been absorbed by an intruded igneous rock. The somewhat slaty and baked character of the amphibolite on the immediate contact bears out this conclusion. In sections of the serpentine at a short distance from the contact the fibrous aggregate structure appears again as in the normal type from other parts of the area.

It should be stated here that the above contact was at first regarded as a simple fault.* That crushing of the serpentine, as well as the amphibolite, has taken place is admitted ; but if the contact is of the nature of a fault alone, brecciation should form a prominent factor in the thin-section. This does not appear, but the phenomena of absorption and infusion of the amphibolite are the prominent features. The fracturing of the serpentine and the adjacent hornblendic rock is to be attributed to a subsequent movement, with which was associated the deposition of the asbestos.

APPLICATIONS OF EMERSON'S VIEWS

An alternative is to be considered in discussing the probable origin of the serpentine. It has been shown by Professor Emerson that orthorhombic pyroxenes develop in limestones by processes of metamorphism and also along contacts of igneous or intrusive masses with lime-magnesia rocks. The question therefore arises with regard to the Belvidere serpentine. Might not the bastite (enstatite) in this case represent a transition stage in a rock, originally sedimentary, high in lime and magnesia and containing a variable percentage of iron ? It has been shown by Professor Emerson † that the above relationships occur in Old Hampshire county, Massachusetts. Moreover, it should be stated that this area lies in the same geological province with the Belvidere area. Emerson also demonstrates that not only the serpentine is derived from the pyroxenic calcareous rocks, but that the amphibole rock—amphibolite—is also a metamorphic product derived from the same series. In other words, both the serpentine and the amphibolite are, according to his interpretation, secondary products resulting from processes of metamorphism of magnesia-bearing limestones, and not of igneous or intrusive masses. The succession of changes from the original sedimentary rock to the final secondary products, as suggested by Emerson, are shown in the following tabulated scheme :

---

* The crushed and broken character of the serpentine observed in the region of the contact on the Tucker property was regarded as sufficient evidence of a true fault, and was so stated in the Preliminary Report of the Vermont Geological Survey, 1903-1904, page 96. Further detailed study of thin-sections makes it reasonably certain that the crushing of the rock was a subsequent phenomenon, which provided favorable conditions for the depositions of the "cross-fiber."

† Monograph xxix, U. S. Geol. Survey, pp. 78-117.

Original rock.	*First stage.*	*Second stage.*	*Third stage.*	
Ferruginous and Argillaceous limestones.	Pyroxenite limestone.	Sahlite serpentine (tremolite).	Serpentine (steatite).	Talc.
	Enstatite limestone.	Enstatite serpentine (actinolite, bastite, tremolite).	Serpentine.	Talc.
	Amphibole limestone.	Amphibolite (epidote).	Serpentine.	Talc.
	Tremolite limestone.	....	....	Talc.
		Olivine serpentine (tremolite).	Serpentine (asbestos).	Talc.

At the present stage of investigation of the Belvidere region it can only be said that neither the amphibolite nor the serpentine has been found in association with limestones or highly calcareous rocks of any sort which would in any respect show an analogy with the occurrences in Old Hampshire county, Massachusetts.

Analyses of Type Rocks and Fiber

An inspection of the following analyses and comparison with those of chrysotile from the Canadian area bring out some significant facts.

Number	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	H_2O	CaO	Total
45........	41.84	....	....	2.23	41.99	14.28	....	100.34
48........	40.57	0.90	....	2.81	41.50	13.55	....	99.33
49........	40.52	2.10	....	1.97	42.05	13.46	....	100.50
1........	39.97	7.27		....	40.78	12.51	0.50	101.03
2........	44.10	....	....	....	43.00	12.90	....	100.00

Numbers 45, 48, and 49 are analyses of chrysotile from Shipton, Quebec, Broughton, and Templeton, and are selected from a series in Dana's Systematic Mineralogy, page 673.

Number 1. Belvidere chrysotile (cross-fiber) from the Tucker prospect; analysis by Mr C. H. Jones, Burlington, Vermont. Both the oxides of iron and the aluminum are included under the 7.27 per cent.

Number 2. Theoretical composition of chrysotile, as given in Dana's Systematic Mineralogy, page 671.

In the Belvidere fiber number 1 it will be noted that the silica runs somewhat lower than is indicated in the Canadian cases and considerably lower than the theoretical limit, while the total alumina and iron is, on the other hand, much higher than in numbers 45, 48, and 49. The iron is probably somewhat high, for the reason that the fiber contains microscopic grains of magnetite tucked away between the films to such an extent that its removal by the use of a magnet may not have been complete.

The mechanical inclusion of the ore would necessarily lessen or lower the percentage of the other constituents.

The analyses of the serpentine, in which the asbestos is included, require brief consideration. To this series is also added the theoretical composition of serpentine as given by Professor Kemp in his "Handbook of Rocks," and two analyses of the amphibolite which forms the crest of Belvidere mountain.

Number	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	Total
1.......	44.14	....	....	....	42.97	....	12.89	100.00
90........	40.21	5.73		....	40.98	0.82	12.68	100.42
35........	40.82	7.63		....	38.40	1.37	12.41	100.63
5........	42.93	32.77		....	5.96	14.29	1.76	97.71
23........	44.36	28.85		....	8.74	11.70	1.71	95.36

Number 1. Theoretical composition of serpentine. Kemp's Handbook of Rocks, page 140.

Number 90. Analysis of serpentine from foot of the serpentine slope, Belvidere mountain.

Number 35. Analysis of serpentine from the upper slope and taken from the property of the United States company.

Number 5. Analysis of amphibolite from the base of the formation CO_2.

Number 23. Analysis of amphibolite from the top of Belvidere present but not determined. It accounts for the low total.

An inspection of the analyses of the serpentine, when considered in the light of the theoretical composition, brings to light some variations needing a word of explanation. It will be seen that the silica runs noticeably below the theoretical limit, and in fact below that usually found in many serpentines derived from pyroxene or olivine rocks. This can be accounted for by the fact that the rock almost invariably shows a large amount of iron ore, and probably by far the greater part of the total estimate of the alumina and iron is composed of iron oxide. This, as in the case of the fiber, would lessen the relative amount of silica in the analysis.

The presence of a small amount of alumina is to be accounted for as well. It is already a recognized fact that alumina cannot be considered as an introduced product, but, to the contrary, must have formed a part of the original rock from which the serpentine was derived. Now, the facts gathered from the thin-sections suggest as the original a rock containing an orthorhombic pyroxene. The very large amount of magnetite precludes a derivation of the pyroxene by metamorphism of limestones or highly calcareous deposits. If this interpretation be correct, we are forced to conclude that the original from which the serpentine was derived must have been some member of the gabbro family. The alumina, therefore, could be derived from the presence of an aluminous pyroxene, or more probably from the feldspar. The calcium could likewise be derived from the same sources. The thin sections suggest that a very large part of the calcium is now present as carbonate. It is not, however, universally present in all sections.

CONCLUSIONS

It is believed that the petrographical facts, as obtained from the thin sections of the serpentine-amphibolite contact on the Tucker property, are sufficiently evident to render the application of Professor Emerson's explanation of similar deposits impossible. It must be admitted that a number of the thin-sections from the serpentine area show an appreciable amount of calcite. But an excess of calcium carbonate is by no means a proof of a derivation from a limestone. It is quite as easily accounted for as a secondary product from pyroxenic contents of an eruptive or igneous mass.

It is also significant in this connection to note that petrographic and chemical investigations of serpentine deposits, both in the United States and other countries, have almost invariably proven that such rocks are derived from some member of the basic igneous series. The accompanying tabulation of explicit statements, culled from the literature, contains but two cases of a derivation from a pyroxenic limestone out of a total number of twenty-six occurrences. While this statement contains nothing of the nature of proof with reference to the area under consideration, it nevertheless reveals the significant fact that the conclusions reached with reference to the Belvidere serpentine are quite in accordance with the predominant views held by the vast majority of petrographers.

Concerning the origin of the amphibolites, I can only say that so far as lithological relationships in the field and petrographical characters are known no data have been found which even offers a suggestion as to the nature of the original rock from which the amphibolite was derived. It is not, however, associated with any argillaceous limestone, such as has been recognized by Professor Emerson, in the Old Hampshire county occurrences.

Locality.	*Analysis derived from.*
Colfax folio, California.........	Peridotite.
Downieville folio, California ...	Peridotite, pyroxenite.
Jackson folio, California.	Peridotite, gabbro, pyroxenite.
Mother Lode folio, California..	Intrusive, original not determinable.
Placerville folio, California.....	Peridotite, pyroxenite.

Locality.	*Analysis derived from.*
Sonora folio, California	Basic gabbro or ultra basic rocks of the peridotite family.
Moriah, New York	Pyroxene.
Aqueduct, New York	
Montville, New Jersey	Saxonite.
Grenville, California	Pyroxene rock.
Mount Diablo, California	Peridotite.
Blandford, Connecticut	Sahlite in limestone (Monograph 29, U. S. G. S.)
Granville, Connecticut	Enstatite in limestone (Monograph 29, U. S. G. S.).
Kamloops, British Columbia	Basic volcanics.
Ishpeming, Michigan	
Roseburg folio	Saxonite and olivine gabbro.
Lassen peak	Dunite.
Holyoke folio	Associated with limestones.
Mosquito range, Colorado	Pyroxene and amphibole.
Russia	Olivine and diallage rock.
Southwest Minnesota	Saxonite.
Roxbury, Vermont	
Manhattan island, New York	Actinolite, tremolite.
Rainy Lake region	Olivine eruptives.
Nevada City and Grass valley, California.	
Sierra Nevada	Gabbro (dike) peridotite.
Coast range, California	Peridotite (see 177*a*).
Marquette region	
Elkhorn district, Montana	Alteration product from diorite.
Baltimore, Maryland	Enstatite olivine rocks.

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RED BEDS OF SOUTHWESTERN COLORADO AND THEIR CORRELATION*

BY WHITMAN CROSS AND ERNEST HOWE

(Read before the Society December 29, 1904)

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PART I. THE RED BEDS OF SOUTHWESTERN COLORADO

INTRODUCTION

The strata of reddish color, in varying tints and shades, often referred to as the "Red beds," constitute one of the most striking terranes in the sedimentary section of the Rocky Mountain province. Consisting in the main of sandstones and conglomerates, beds of other character, such as shale, limestone, gypsum, etcetera, are more or less prominent in many localities. While the complex in question is one of wide distribution and has been examined and described by many geologists, it is still very imperfectly known as to its age and the correlation of the sections of different areas. The rarity or absence of fossils, the varying vertical extent of the red color, and the common lack of stratigraphic evidence suggesting division planes combine to make a satisfactory analysis of the Red beds difficult.

Where the complex in question has what may be called its normal development it is 2,000 feet or more in thickness. It occurs in numerous districts between known Carboniferous and Jurassic beds characterized by fossils. This general stratigraphic position and the lithologic similarity to the Triassic beds of the Atlantic slope has led to the prevailing reference of the Red beds to the Trias. This reference was early shown to be correct in certain regions and for certain strata by the discovery of Triassic fossils, while in other places Carboniferous fossils have shown that the color distinction is not a safe guide, and that some portions at least of the Rocky Mountain Red beds belong to Permian or Pennsylvanian series. These facts show the necessity for the careful study of each district and for due caution in correlation.

The present paper is primarily a contribution to the knowledge of the Red beds as developed in the San Juan region of southwestern Colorado, and this is accompanied by a partial review of existing literature and such discussion of correlation as seems justified at this time.

LITERATURE CONCERNING SAN JUAN "RED BEDS"

Reconnaissance explorations.—The Red beds of the San Juan region received but little attention from the reconnaissance explorers who preceded the geologists of the Hayden Survey. In 1859 J. S. Newberry, with the Macomb expedition, camped on the Animas river a little above Durango, but the only excursion made from that point appears to have been to the south, down the river, and the excellent section of lower Mesozoic and Paleozoic rocks exposed on the river banks for several miles to the north escaped examination by this keen observer. Had Newberry studied with care any section of the Red beds in the Animas valley, we should doubtless have had, thus early, a valuable comparison with the Triassic section of northern New Mexico, where he had discovered fossiliferous horizons containing many plants and a number of vertebrates. As it was, Newberry merely noted the fact that "the hills just above our camp are composed of red sandstone and conglomerate (Triassic), very much disturbed" (33,* page 81).

In 1873 the Animas Valley section was crossed by the Hawn brothers accompanying an expedition under Captain Ruffner and by J. J. Stevenson, of the Wheeler Survey. The former merely refer to red sandstones without mention of their probable age, except as shown that they come above fossiliferous Carboniferous strata (of the Hermosa Pennsylvanian) (17, page 68). The latter gives a thickness of 1,500 feet to the red strata of the Trias and says that they abut against the Carboniferous (38, page 378)—a statement which we believe can only refer to a relation existing along an east-west fault observed by us east of Engineer mountain.

The first of the Hayden Survey geologists to observe the San Juan Red beds was F. M. Endlich in 1874. He examined them in the Animas, Dolores, and San Miguel valleys, and refers to their presence in the Uncompahgre canyon, which "is considered inaccessible." Endlich assigns the red strata between the fossiliferous "Middle Carboniferous" (Hermosa) and the "Lower Cretaceous" sandstone [meaning the La Plata, now assumed to be Jurassic] to the "Upper Carboniferous," and states that "Trias and Jura are missing or reduced to a minimum and only exposed locally" (12, page 215). This last qualification is but a general saving clause, for he nowhere refers to observed Triassic or Jurassic beds and in fact remarks in another place that "without the appearance of either Triassic or Jurassic we find the Cretaceous sandstones belonging to No. 1 [Dakota] resting immediately upon the red Carboniferous sandstone. No transitory formations whatever are in sight between the two," etcetera (12, page 222).

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*The numbers refer to the bibliography at the end of this paper.

The reference of the San Juan Red beds to the Upper Carboniferous was due to the discovery by Endlich in 1873 of fossils in the reddish, limestone-bearing section of the Arkansas valley and Sangre de Cristo range. Indeed, he provisionally correlates the San Juan strata with this formation—his "Arkansas sandstone" (12, page 240). On the Hayden map Endlich represents the "Upper Dakota" as resting on the "Upper Carboniferous." In this division of the section it is plain that the Jurassic Gunnison group (La Plata and McElmo formations) is included in the "Upper Dakota," and that the "Upper Carboniferous" consists of the Red beds.

In 1875 W. H. Holmes examined the country west of Endlich's territory of the previous year, and the Hayden map shows two formations namely, "Lower Dakota" and "Trias," interpolated between "Upper Carboniferous" and "Upper Dakota." The sections studied by these two geologists are, however, practically the same and the overlaps indicated by the Hayden map simply show the method of adjustment adopted in compilation. The Red beds are referred to the Trias by Holmes in his report (23) without special discussion of the question. Except in the zone bordering Endlich's field, no area examined by Holmes and actually occupied by Red beds is colored as "Upper Carboniferous" on the Hayden map.

The Red beds near Ouray were hastily examined by A. C. Peale in 1875. In his report he refers to them as above the Carboniferous and says that "above them is the Dakota sandstone" (35, page 41). He, however, recognized the Jurassic (or McElmo beds) as present beneath the Dakota on the north side of Dallas creek, beyond a fault, and the final map, in the Hayden atlas, represents Trias, Jura, and "Lower Dakota" as present at Ouray. The strata now under discussion undoubtedly comprised the Triassic section of Peale.

An important contribution to knowledge of the San Juan Red beds was made by R. C. Hills in 1880 (20) and 1882 (21) in the discovery of vertebrate, invertebrate, and plant remains in the San Miguel valley. The locality of this discovery is about 1½ miles below the present site of Telluride. The vertebrate remains consisted principally of teeth belonging to a belodont crocodile, and one specimen represented a ganoid fish similar to *Catopterus gracilis*. One small gasteropod shell was found and several apparently determinable species of plants were obtained. Unfortunately, these fossils, which had been submitted by Mr Hills to paleontologists for determination, were lost before a final report upon them was made. The remains were found near the top of the Red bed section of the San Miguel valley, within 100 feet of the white Jurassic sandstone.

Work of the United States Geological Survey.—A systematic study of the San Juan mountains and adjacent territory for the purpose of folio mapping began in 1895, in the Telluride quadrangle, and is still in progress. Previous to the field work of the past season the Red Bed section had been examined in the San Miguel, Dolores, and Animas valleys and in the La Plata mountains, covering the entire area where the section is exposed on the west and south slopes of the San Juan mountains, excepting a small district east of the Animas river. The results of these investigations as to the Red beds have been published in the Telluride (3) and La Plata (4) folios and in a report on the Geology of the Rico mountains (5), by Cross and Spencer, and will now be summarized.

During the Telluride work the fossiliferous horizon in the San Miguel valley, discovered by Hills (20, 21), was easily found, and it has been identified, lithologically or by fossils, throughout the area thus far examined, wherever the Red Bed section is complete. In the study of the Rico mountains invertebrate fossils were found in the lower 300 feet of the Red beds, a fauna very closely allied to that in the underlying Carboniferous formation. This discovery was made before the Telluride folio was issued in 1899. The character of the sedimentary section in the La Plata mountains was also known before that time.

In the Telluride folio the entire Red Bed section of that quadrangle was referred to a single formation, the Dolores, with the statement that the section was known to be incomplete, and with an allusion to the lower fossil-bearing Rico formation. The Dolores formation was defined as follows:

> "It is desired to apply the name Dolores to the Triassic strata of southwestern Colorado and of adjacent territory so far as a direct correlation may prove to be practicable."

After reference to the known Triassic fossils and the extent of the section assigned to the Dolores in the Telluride folio, the provisional nature of this assignment was pointed out in these words:

> "Whether or not all the beds now associated in the Dolores formation are really of Triassic age remains to be determined by further discoveries."

The Red beds are again referred to the Dolores formation in the La

Plata folio (4), with provisional inclusion of the lower unfossiliferous member of the section. Reviewing the conditions, it is remarked:

> "It is evident that future discoveries may not only place the upper boundary of the Rico formation at a higher horizon, but may also establish an intermediate Permian formation between the Rico and the Dolores."

The Rico formation is not exposed in the La Plata quadrangle.

In the report on the Geology of the Rico mountains the following characterization of the Rico formation and its relations was given:

> "It is here proposed to apply the name Rico to a formation assumed to be about 300 feet in thickness, occurring between the Hermosa or characteristic Pennsylvanian Carboniferous and strata assigned at present to the Trias of the San Juan region, the Dolores formation. It is made up of sandstones and conglomerates, with intercalated shales and sandy fossiliferous limestones. In its lithological features it resembles the strata immediately above it, but its fossils are distinctly of Paleozoic age, and while many of its forms are common to the Hermosa formation, others are of Permian type, so that it seems proper to designate its age Permo-Carboniferous [Permo-Pennsylvanian], to indicate that it is transitional between these divisions of the Carboniferous system. In the Rico region the formation is conformable upon the Hermosa and is followed by the Dolores with seemingly perfect parallelism of stratification. The fauna as a whole has an aspect quite different from that of the Hermosa, since it is largely composed of lamellibranchs as opposed to the brachiopod assemblage of the lower formation. The boundary between the Rico and Dolores formations is at present entirely artificial, being based upon the highest known occurrence of the Rico fossils. The former is made to include only strata characterized by the Rico fauna, while the latter comprises the apparently unfossiliferous medial portion of the Red beds, together with the upper part of known Triassic affinities. The actual age of the unfossiliferous Red beds is thus left in doubt. They may eventually prove to be either Permo-Carboniferous, true Permian, or Trias. They correspond to [a part of] what has been called Trias throughout the Rocky Mountain province" (5).

The remainder of the Red Bed sections about Rico was referred to the Dolores with the provision that the name should apply to Triassic strata and expression of doubt as to the age of the unfossiliferous beds, in harmony with the treatment of the subject in the Telluride folio. The fossil-bearing and fossil-free parts were described separately.

It was further pointed out that the unfossiliferous Red beds corresponded in position and character to strata assigned by various authors to the Permo-Carboniferous or the Permian, in the adjacent Plateau province of Utah and Arizona and in other localities.

The views expressed in the Rico report on the age and relations of the Rico formation were based mainly on the opinion of G. H. Girty as to the invertebrate fauna. That opinion was more completely stated by Girty in his full discussion of the Carboniferous faunas of Colorado (15). The more recent work in the San Juan region, and especially in the Animas valley, has shown that the Rico formation is not a persistent feature of the Red Bed section, nor its fauna so markedly distinguishable from that of the Hermosa beds as was seemingly the case from observations in the Rico mountains. At even a few miles distance to the east or southeast from that district, the transition from the unfossiliferous Red beds to the Hermosa is no longer through a marked reddish zone 300 feet in thickness. The Rico fossils are found in certain peculiar limestones, plainly to be correlated with those so marked in the Rico formation, but these fossil-bearing strata are not necessarily intercalated in a red section and are limited to a very narrow band. Moreover, there is mingling of forms supposed originally to be characteristic of the Rico with those of the Hermosa. These observations make the Rico formation a local development, having less importance in the analysis of either the Red Beds or the Carboniferous section than was at first assigned to it. Further reference to this question will be made in discussing the correlation of the San Juan formations.

THE OURAY UNCONFORMITY

As was long ago made plain by the Hayden maps of southwestern Colorado, the western San Juan district is a center at which a domal elevation of Paleozoic and Mesozoic sediments took place at the close of the Cretaceous. Earlier movements of a similar character also took place at this center, their effects being with difficulty distinguishable from those of the post-Cretaceous uplift. The domal structure is well shown by the attitudes of the strata in the deep valleys of the Animas, Dolores, San Miguel, and Uncompahgre rivers, which radiate from a central area now occupied mainly by volcanic mountains. There was practically a planation of the apex of this dome before the earliest volcanic tuffs were deposited, so extensive that granites, schists, and Algonkian sediments were exposed by that planation, and these rocks have now been once more revealed, to some extent, on both the northern and southern sides of the mountains, through the removal of the volcanics. A review of San Juan structure may be found in the Telluride folio (3), and this broad subject will not be further discussed in this place.

The Uncompahgre valley exhibits the only extensive section of the sedimentary rocks to be found on the northern slope of the San Juan. That condition is mainly due to the fact that to the east of the valley the Paleozoic and early Mesozoic beds were removed as a result of pre-Triassic and pre-Jurassic uplifts and succeeding erosion, while in the Tertiary period the Cretaceous beds were also to a great extent eroded, so that in some places the volcanics rest on gneiss or schist.

At Ouray the Uncompahgre issues from a deep gorge cut in Algonkian quartzites and slates, crosses a fault along which the lowest Paleozoics are steeply upturned against the Algonkian series, and thence flows northward in the general dip line, exhibiting in its banks the entire sequence of beds, as high as the coal-bearing portion of the Cretaceous. Just as the river crosses the fault mentioned it is joined on the west by Canyon creek, an important tributary, and by Oak creek, a smaller one. On the eastern side, opposite Canyon creek, is a splendid glacial cirque, called "The Amphitheater," the town of Ouray being situated on the alluvial fans deposited by the streams from that deep recess.

The northern walls of Canyon creek and of the Amphitheater come close together immediately below Ouray, and the Uncompahgre once more flows in a canyon for 2 miles, the walls rising abruptly for 3,000 feet and exhibiting fine sections of the sediments as high as the Mancos Cretaceous shales, above which come the volcanic tuffs. These cliffs, and especially those facing the town of Ouray, are already celebrated among tourists for their rugged forms and attractive coloring and must in future be classic ground to the student of Colorado geology, because in them is so clearly revealed one of the most important unconformities of the province, evidence which will be of great assistance in solving a long debated point in Rocky Mountain stratigraphy.

It was stated by R. C. Hills in 1882 (21) that the fossiliferous Triassic horizon observed by him on the western and southern slopes of the San Juan was absent in the Uncompahgre section. This is an error, however, as the study of the Ouray quadrangle by the authors during the season of 1904 showed that the Dolores Triassic formation, though very thin, is present in the Uncompahgre valley, and is there separated stratigraphically from the underlying Red beds by a pronounced angular unconformity. This important stratigraphic relation has hitherto escaped recognition, apparently through the difficulty of reaching the places where it is most clearly demonstrable, and owing to the apparent conformity within the Red beds as they dip beneath the valley. The angular unconformity to be described is, however, visible for some miles from certain directions, and only the circumstance that no detailed work has ever before been done in the Ouray district can explain the delay in recognizing the relations here under discussion.

The views of plates 82 to 85, with the explanations afforded by the accompanying diagrams, show perhaps more clearly than word pictures can do the position of the unconformity and its pronounced character. Plate 82 shows how plainly the unconformity stands out, as seen from the northern slope of Canyon creek at a distance of 5 miles. The dark wedge-like mass in the cliffs near the Amphitheater consists of

Hermosa Pennsylvanian strata, and the plane truncating them is at the base of the Triassic conglomerate. This view also brings out the discordance between the San Juan tuffs and the sediments. The tuff line descends from a level of 10,400 feet on the crest of the ridge south of Cascade creek to somewhat below 9,100 feet, the elevation of its lowest exposures at the back of the Amphitheater. The tuff thus cuts off the Dakota, McElmo, La Plata, and Dolores formations and a considerable part of the Hermosa. The irregular plane of pre-volcanic erosion causing these relations dips in general easterly, away from the point of view.

Plate 83 is a nearer view of the cliffs east of Ouray, where the unconformity is so well exposed. By means of the diagrammatic explanation the structure may be rendered clear.

The cliff section of this view is chiefly composed of light reddish strata, in varying tints and shades, up for 1,200 feet above Ouray ; yet the bright red, almost a vermilion, so characteristic of the Red beds in general is absent, and simply because the horizons to which that strong red color is normal are not present. From the base of the lower fall of Cascade creek to the point adjacent to the Amphitheater (shown in the oversheet) where the Triassic conglomerate appears, the strata all belong to the Hermosa Carboniferous. The more massive beds are pink grits and sandstones. Alternating with them occur gray limestones or calcareous shales carrying the characteristic Pennsylvanian fauna. The red color of this section is unusual in the Hermosa formation of the San Juan, and apparently marks a transition to the still stronger color exhibited by the Maroon formation of the Elk mountains.

The plane of unconformity is easily reached by approaching from the Amphitheater side, and, as there is commonly a ledge below it, one can trace this horizon almost continuously across Cascade creek and as far as the southern border of the Blowout recess. At the angle of the cliffs nearest the Amphitheater, seen in plate 83, the unconformity appears between a band of dark, reddish purple beds, consisting of thin limestones and calcareous shales, highly fossiliferous, and the thin Triassic conglomerate. The latter is in general of dark gray or reddish color, carries numerous pebbles of limestone a small fraction of an inch in diameter, with varying amount of sand and gravel. Cross-bedding is prominent and the stratum is thoroughly characteristic of the limestone conglomerates appearing in the Dolores formation all through the San Juan. Small fragments of bone were observed, but such remains seem less abundant than elsewhere.

The Carboniferous beds near the Amphitheater strike north 65 degrees east and dip 12 degrees northwesterly. The Triassic strata have a strike which is nearly the same and dip 5 or 6 degrees, also northwesterly.

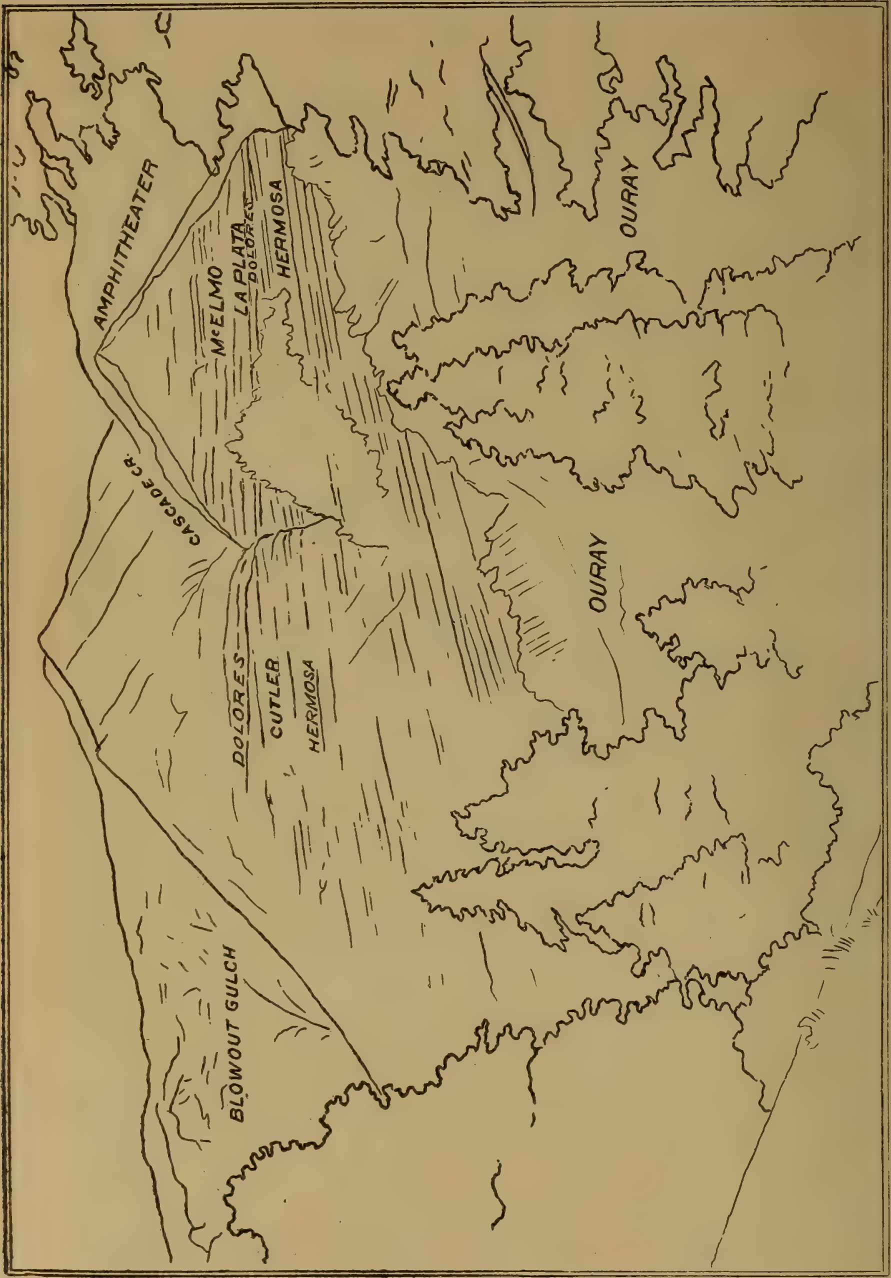
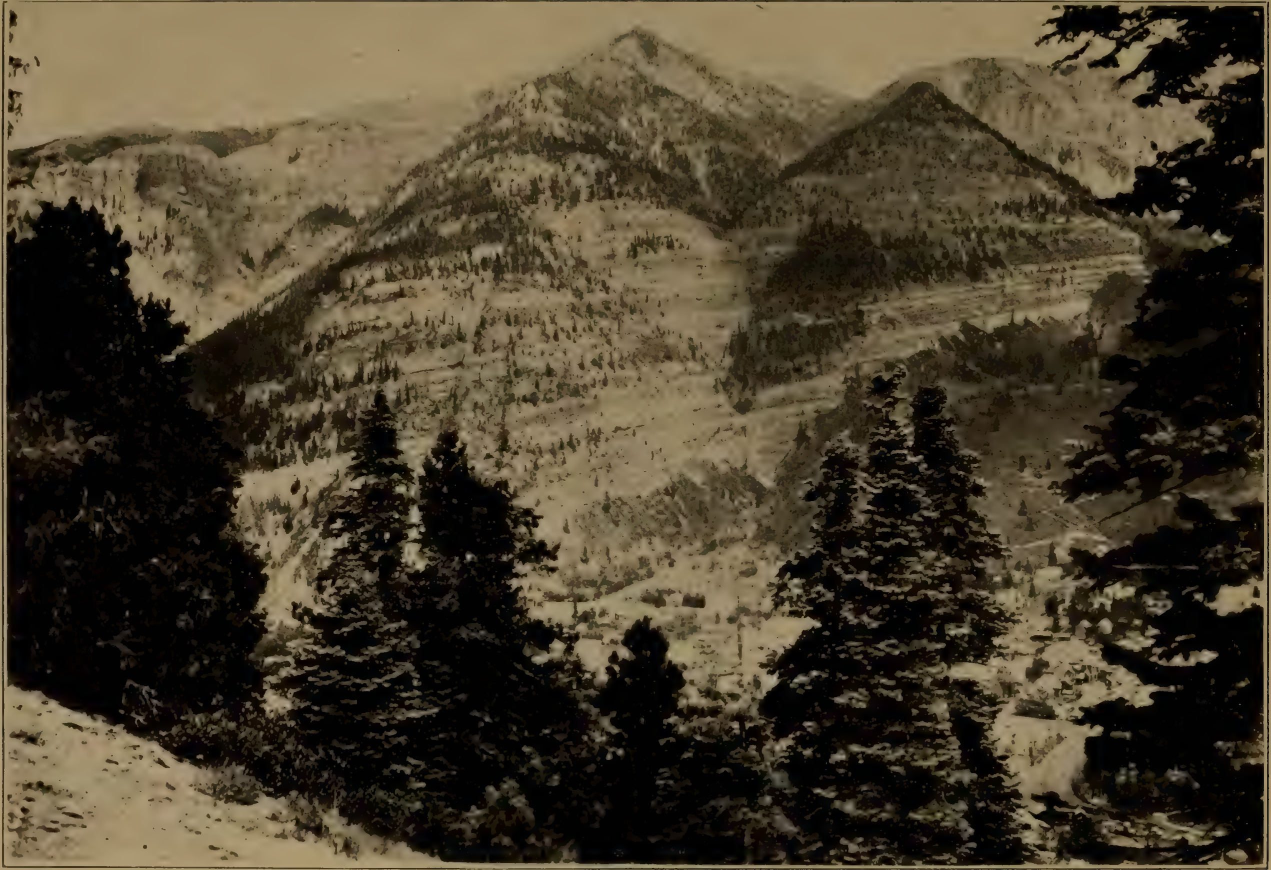

AMPHITHEATER
McELMO
LA PLATA
DOLORES
HERMOSA
OURAY
CASCADE CR.
OURAY
DOLORES
CUTLER
HERMOSA
BLOWOUT GULCH

FIGURE 1.—EXPLANATION OF PLATE 82

View looking down Canyon creek toward the Amphitheater and the cliffs on its northern side, where the unconformity between the Dolores and Hermosa formations is exhibited



THE TRIASSIC UNCONFORMITY AT OURAY

This discordance in dip continues through the cliff face almost to the Blowout creek, as is clear from plate 83.

In plate 84 is reproduced a view of the unconformity in the cliffs either side of Cascade creek, as seen from the cliffs above Ouray on the west side of the river and north of Oak creek. The point of view is but little below the plane of unconformity and the discordant, greater dip of the Carboniferous strata is very evident.

In following the unconformity from the Amphitheater northwest it is found that the strata below the Triassic conglomerate belong to the Hermosa formation nearly to Cascade creek. Just before reaching that stream a massive pale reddish sandstone appears, the highest fossiliferous bed of the Hermosa occurring directly under it. This stratum of sandstone is approximately 100 feet thick, exceptionally massive, and as a similar bed appears likewise on the west side of the Uncompahgre, just above the uppermost fossil-bearing limestone, the base of this red sandstone is assumed as limiting the Hermosa formation.

The heavy sandstone just mentioned underlies a wooded bench on the shoulder adjacent to the Blowout, and it is there separated by only a few yards from the Triassic conglomerate above it. Beyond this point, on the east side of the river, the relations are obscured for some distance through the Blowout porphyry intrusion and a great amount of landslide and other debris, and we now turn to the exposures on the west side of the Uncompahgre as best illustrating the relations of the Triassic to the Red beds proper of this district.

On the northwest of the town of Ouray rise cliffs even more precipi, tous than those to the east, but not quite so high. The lower half of these cliffs exhibits Hermosa strata, but the upper part contains many sandstones and shales of stronger red tones than can be found in the Cascade Creek section. No unconformity appears in these cliffs as seen from the east. On searching for the Triassic horizon, it is found a little above the main cliffs and below a pronounced bench of glacial molding. This bench is carved at about the Triassic horizon, descending gradually northward with the dip of the strata. Its floor is uneven in detail, more or less debris-covered and timbered, but the white La Plata sandstone outcrops in many places just back of it, and the Triassic conglomerate appears below it, within a few yards in most places. Where this bench begins, on the north side of Oak creek, the Triassic conglomerate occurs at about 8,900 feet, the same level it occupies adjacent to the Blowout on the east; but fossiliferous strata of the Hermosa do not underlie it here, and in fact 400 to 500 feet of grits, conglomerates, and deep red sandy and micaceous shale intervene before the Hermosa limestones appear. The Hermosa and overlying Red beds in the cliffs dip 15 to 20 degrees

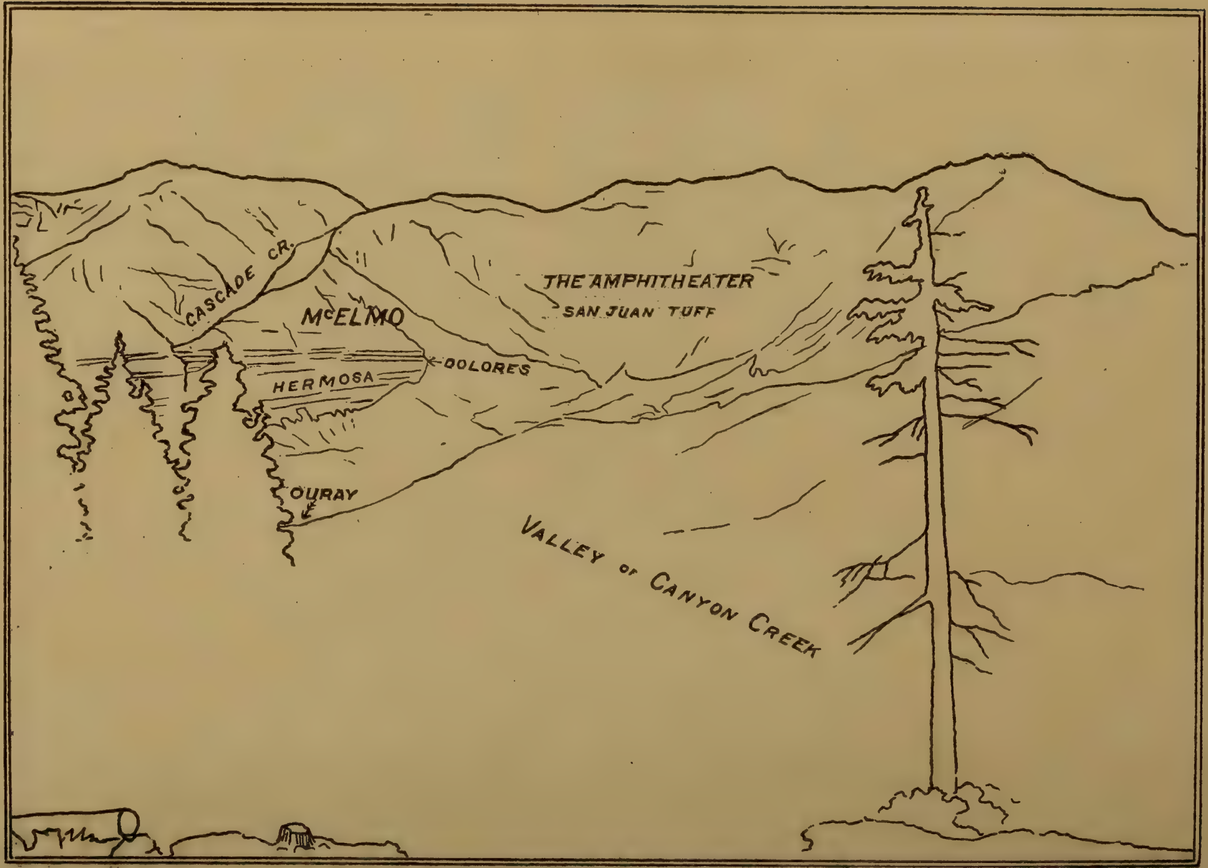
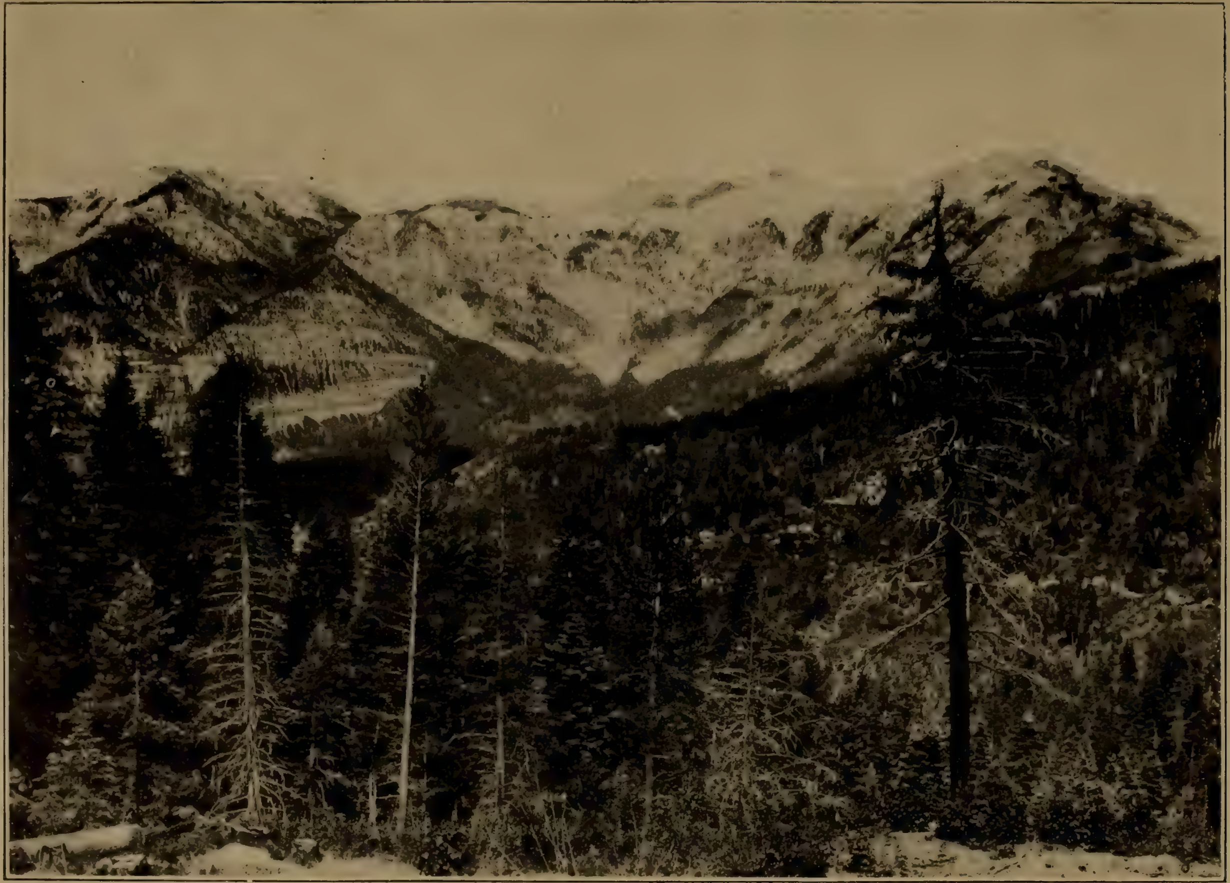

CASCADE CR.
McELMO
THE AMPHITHEATER
SAN JUAN TUFF
DOLORES
HERMOSA
OURAY
VALLEY OF CANYON CREEK

FIGURE 2.—EXPLANATION OF PLATE 83

View looking across the Uncompahgre valley at Ouray, toward the cliffs between the Amphitheater and the Blowout, showing the position of the plane of unconformity between the Dolores and the Hermosa and Cutler formations



THE TRIASSIC UNCONFORMITY AT OURAY

almost due north, and it is plain that a monoclinal fold is necessary to bring the top of the Hermosa to the horizon it occupies beneath the Triassic conglomerate east of the river. This fold, of general north-south axis, must have been situated where the present canyon of the river is cut, and hence is not visible. The greater fold, soon to be described, probably obscures this canyon plication in its northward extension.

The northward dip of the strata below the Trias is disturbed by a sharp monoclinal fold with northwest-southeast axis and northerly pitch, which crosses the Uncompahgre canyon shortly below Ouray. The visible portion of this fold is mainly within the unfossiliferous Red beds, and as the Triassic and overlying strata are not affected by it the relative age of the movement is plain. The fold brings 1,000 feet or more of beds of deep red color to light between the Triassic and the Hermosa and shows the magnitude of the unconformity in striking manner. On account of local topographic features the unconformity is less evident above this fold than in the cliffs near the amphitheater.

Plate 85 shows the fold on the west side of the river back of the American-Nettie mill. The diagram opposite shows where the line of the unconformity runs, and an observer stationed at about the Triassic horizon on the eastern side of the river, as, for instance, on the bench where the workings of the Bright Diamond mine are situated, can readily perceive that the Dakota and La Plata limestones do not take part in the sharp fold, and at some points the actual unconformity can be clearly seen. From the cliff adjacent to Oak creek to Corbett gulch the Mesozoic strata dip at about 6 degrees.

To the north of Corbett gulch (see plate 85) the Paleozoic and Triassic beds come into such close approximation to conformity that careful observation is required to detect discrepancies in strike and dip which actually occur. There are minor, gentle, pre-Triassic folds in the Paleozoic beds, but other similar structures are evident in which the Mesozoic strata take part and the unconformity is thus easily overlooked. At about 7 miles north of Ouray the Triassic and lower Jurassic (La Plata) beds dip beneath the alluvial plain and are not again exposed in the Uncompahgre valley. Very good outcrops of both these formations occur on the eastern bank, and near where a diabase dike cuts them, but little above the floodplain of the valley, the basal conglomerate of the Trias contains bone fragments and some belodont teeth. This is at about 100 feet below the La Plata sandstone. Their presence at this point was first noted by H. S. Gane in 1895.

DESCRIPTION OF FORMATIONS

Cutler formation—Selection of name.—The preceding account of the Ouray unconformity will have made plain that no further reason

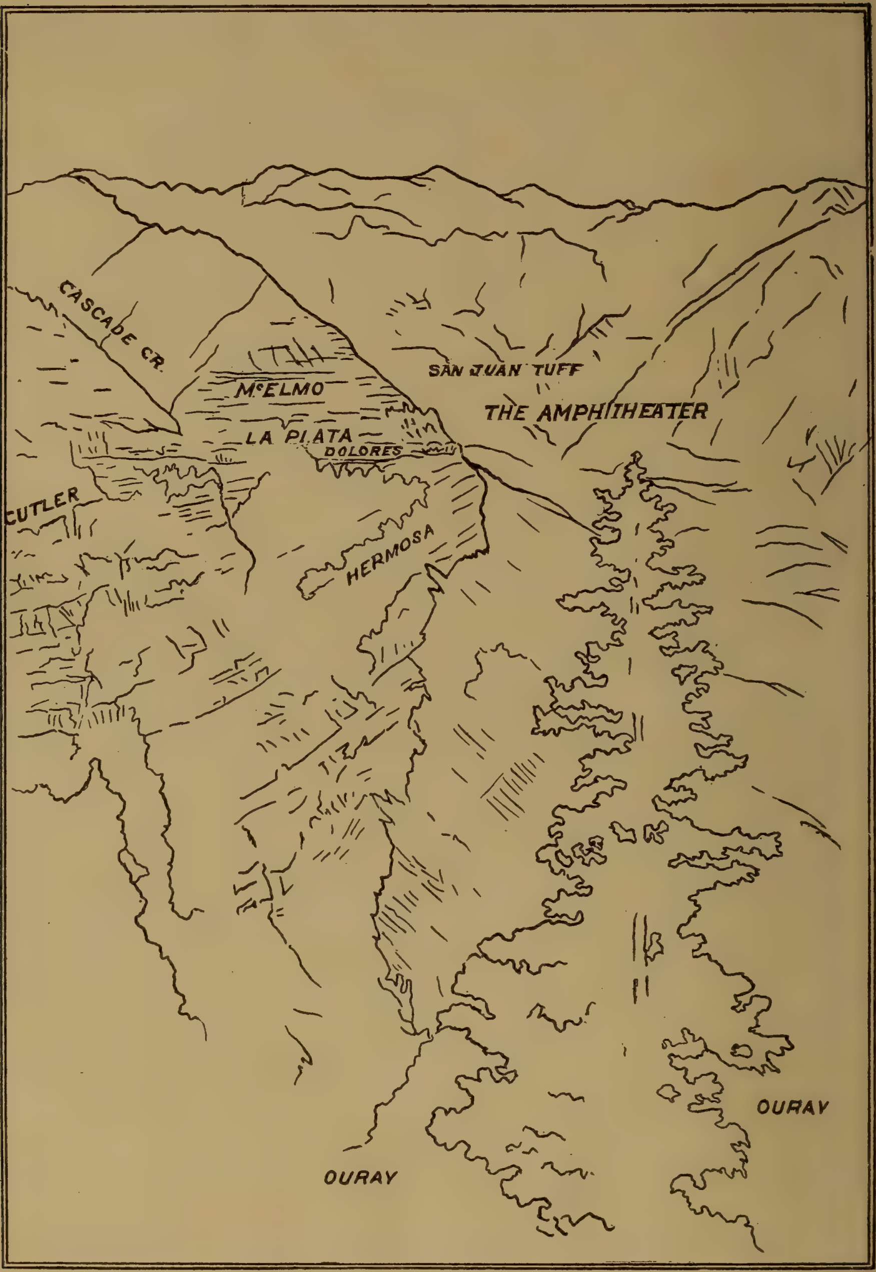
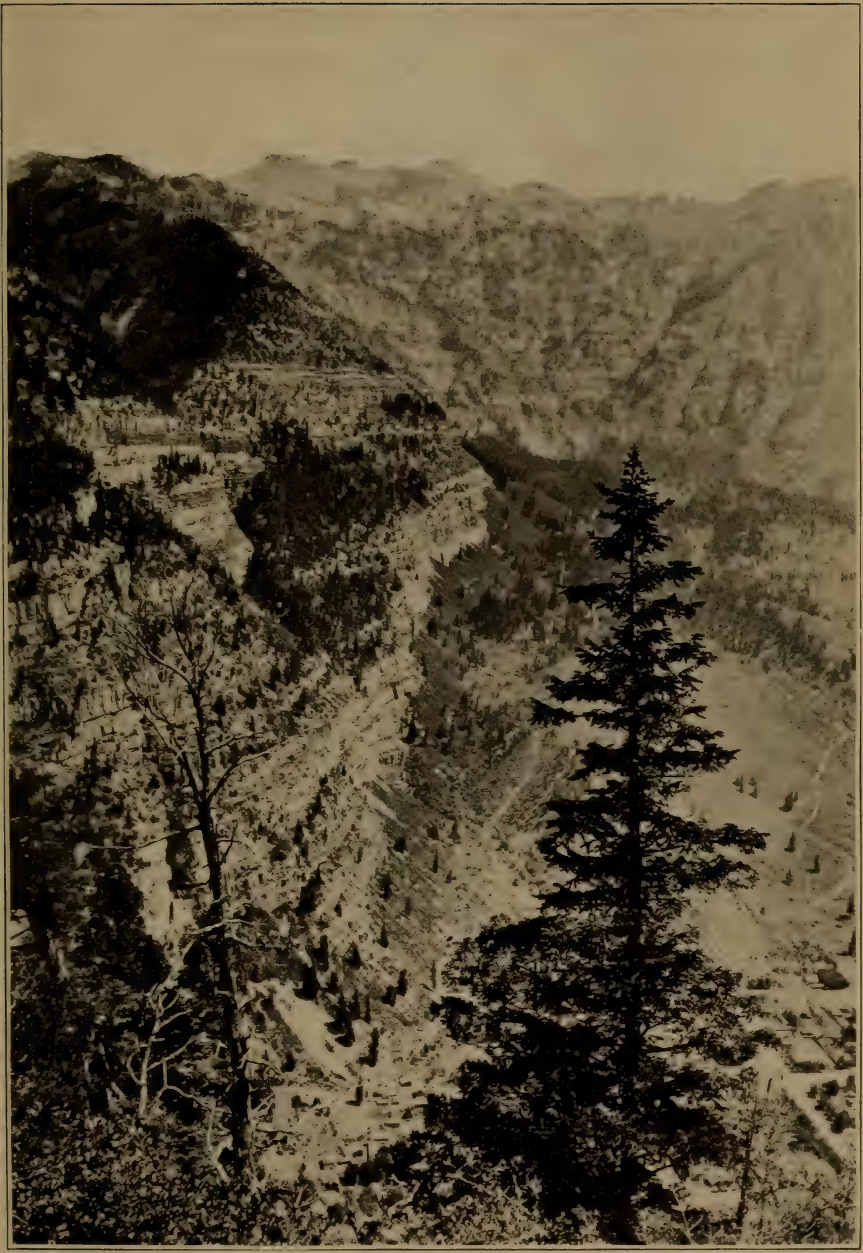

CASCADE CR.
McELMO
SAN JUAN TUFF
THE AMPHITHEATER
LA PLATA
DOLORES
CUTLER
HERMOSA
OURAY
OURAY

FIGURE 3.—EXPLANATION OF PLATE 84

View looking across the Uncompahgre canyon at Ouray, toward the cliffs either side of Cascade creek. The point of view is nearly in the projected plane of the unconformity



THE TRIASSIC UNCONFORMITY AT OURAY

exists for including within the Dolores formation the red sandstones, shales, conglomerates, etcetera, occurring below the well marked horizon of the "Saurian conglomerate." The contingency provided for in the original definition of the Dolores (page 451) has arisen and the subjacent portion of the Red beds, as far as the uppermost Rico or Hermosa horizon, must be distinguished as a separate formation. It seems appropriate to name this stratigraphic unit from the district where its true relations to the Dolores are most clearly exhibited. Since the terms Ouray and Uncompahgre have already been applied to other formations, we have named these lower Red beds after *Cutler creek*, an eastern tributary of the Uncompahgre, entering it some 4 miles below Ouray, at the old settlement of Portland. The bright red sandstones and shales of the Cutler formation are very prominent beneath the Triassic conglomerate on the north side of Cutler creek and the angular unconformity is there very plain, though less pronounced than at the localities described. Near the mouth of the creek several of the heavy conglomerate bands are well exposed.

The name Cutler formation has already been used in the Silverton and Needle Mountains folios, now in press.

As a groundwork for the remarks on correlation, which appear in the second part of this paper, it seems desirable to review the characters exhibited by the Cutler, Dolores, La Plata, and McElmo formations, as observed in the San Juan region.

The last two do not strictly belong to the "Red beds," but assume reddish colors in some places to be referred to, and in the discussion of correlation it will be necessary to note the probable equivalents of the La Plata and McElmo formations in certain districts.

General characterization.—The Cutler formation embraces somewhat more than the lower half of the Red beds section of southwestern Colorado. Its strata are variably red in color and include sandstone, arkose grit, conglomerate, shale, and limestone. The maximum observed thickness is about 1,600 feet.

The formation seems conformable with the underlying Pennsylvanian beds, but above it occurs a stratigraphic break with at least local unconformity. The base of the formation is indicated by the Pennsylvanian fossils of the Hermosa or Rico formations and in a broad way by the color line. No fossils have been found in the Cutler beds.

Details of lithologic character.—Great variability in lithologic constitution, both vertical and lateral, is one of the most striking features of the Cutler formation. The sandstones are sometimes fine grained and massive, but bedding is ordinarily distinct and few homogeneous beds exceed 10 or 15 feet in thickness. All strata are calcareous, and the finer

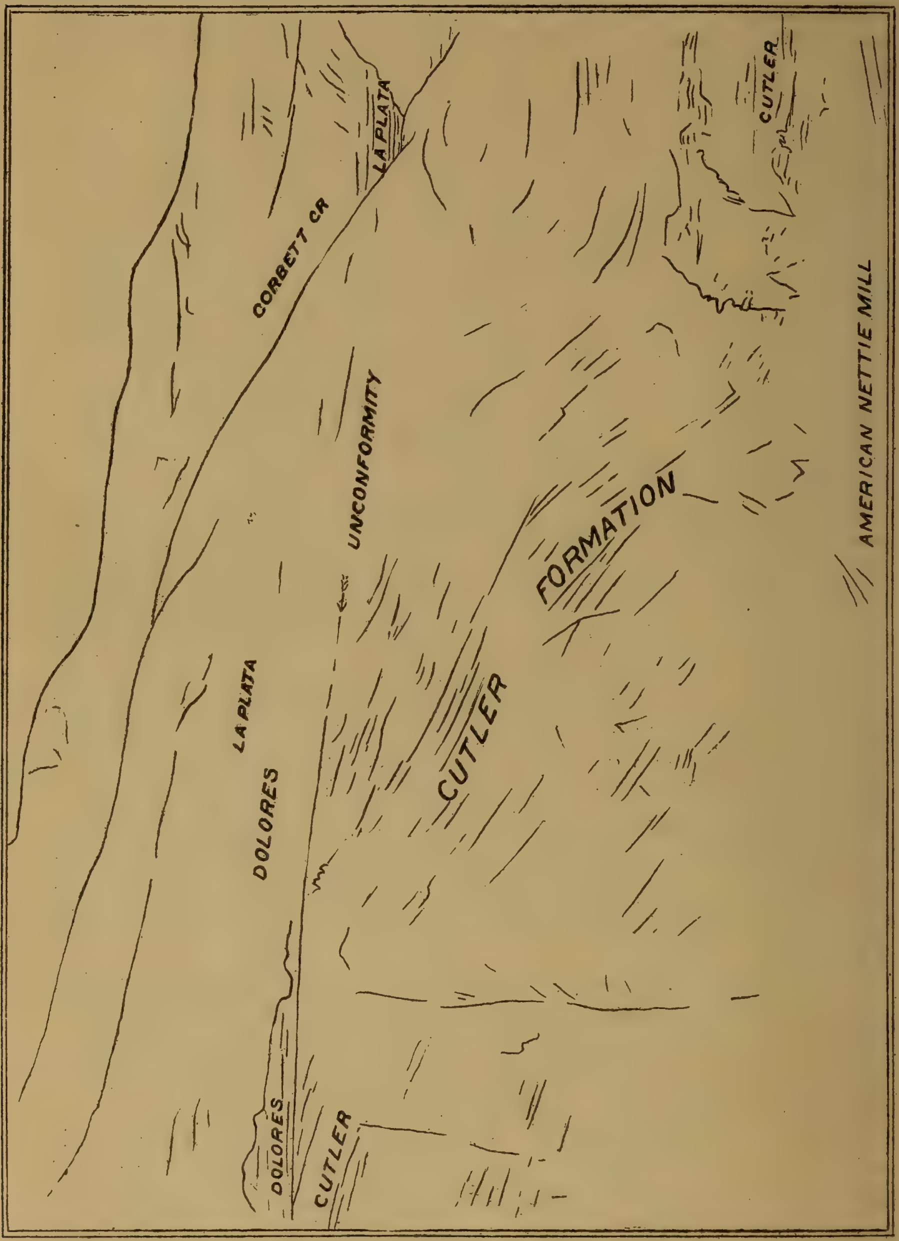
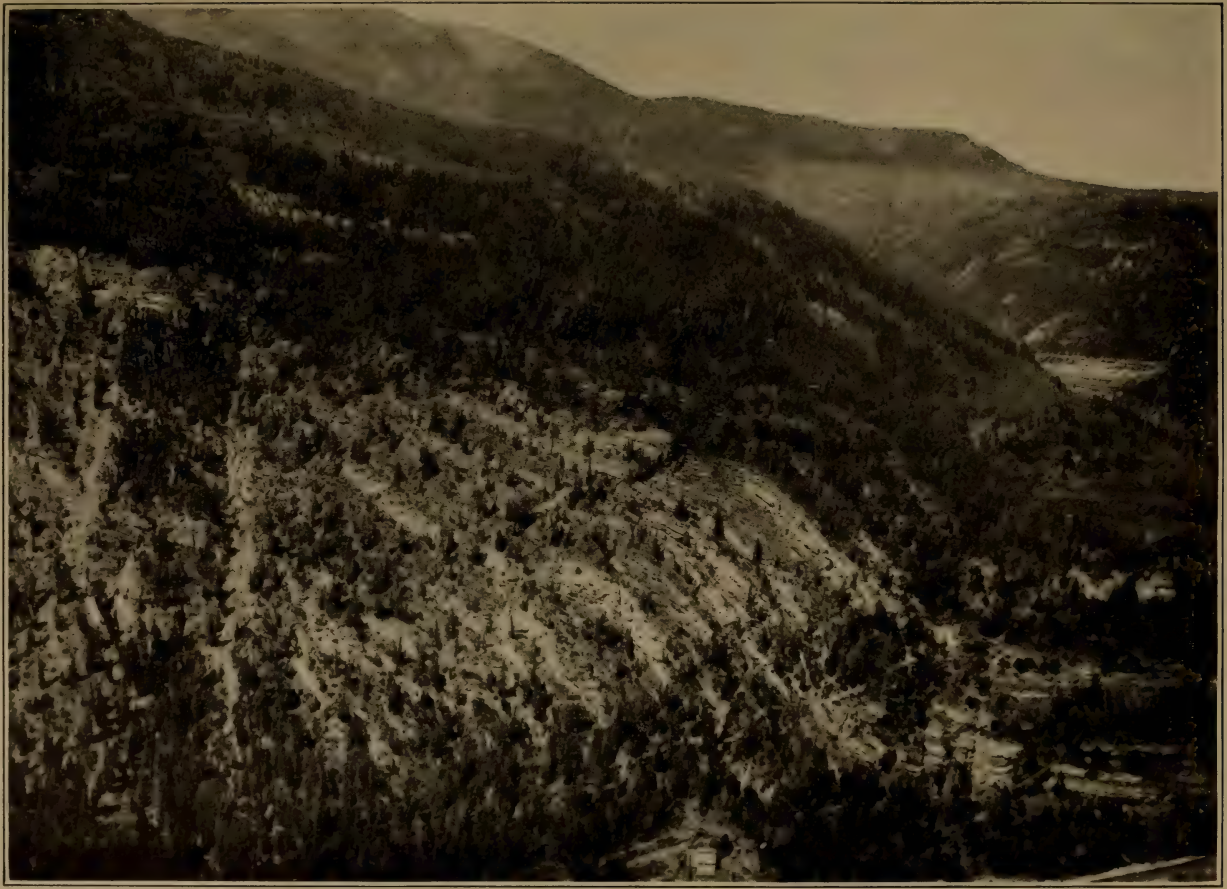

LA PLATA
CORBETT CR
UNCONFORMITY
LA PLATA
DOLORES
CUTLER
FORMATION
CUTLER
AMERICAN NETTIE MILL
DOLORES
CUTLER

FIGURE 4.—EXPLANATION OF PLATE 85

The Triassic unconformity in the cliffs on the west side of the Uncompahgre, above the American-Nettie mill, as seen from near the Bright Diamond mine, on the east side of the river



THE TRIASSIC UNCONFORMITY AT OURAY

grained sandstones grade into calcareous shales and impure marls or into sandy limestones. These rocks are naturally more or less friable and crumbling.

The finer grained strata are of the strongest red color, which is due to a ferritic pigment, and they are also commonly characterized by abundant bronze or rusty mica, which renders them fissile. Clay beds are rare, as is massive limestone. Commonly the more calcareous strata are nodular or gnarly and grade into calcareous sandstones. Greenish and grayish tints are locally found in the nodular limestones and a mottling with red is common. Some of the nodular limestones appear to be intraformational conglomerates.

The sandstones frequently grade into arkose grits and these into conglomerate. With increasing coarseness of grain the red changes to pink, and locally beds of coarse grit are gray or almost white. In other cases the finer matrix of grits and conglomerates is dark red. The cement of the strata is calcite, and most of the conglomerate and arkose beds are comparatively resistant to weathering and form prominent ledge outcrops on all steep slopes.

The grit beds often reach 35 feet in thickness. They are variably massive, being in some places almost homogeneous from top to bottom, while more frequently divided by several thin shale or sandstone layers. Cross-bedding is almost universal. Sporadic pebbles are present in all grits, and with their increase the stratum becomes a conglomerate.

The sandstones are mainly quartzose, the grits contain much feldspar, mica, and small pebbles like the larger ones of the conglomerates. The latter contain pebbles of granite, gneiss, and various schists, of quartzite and limestone, of greenstone and porphyry, and many of red, pink, smoky, or white quartz, part of which may come from veins.

The pebbles are in general larger near the San Juan mountains. Boulders a foot in diameter are occasionally present, but most pebbles are only a few inches in diameter. The relative abundance of different rocks among the pebbles varies according to locality. The greenstone schists, metadiorite, and green porphyry are most abundant in the Uncompahgre valley exposures; granites and quartzites are always prominent.

Taking the formation as a whole, the grits and conglomerates comprise about one-third or less of its total thickness in the quadrangles surveyed, and they are distributed throughout the section. It may be assumed that as distance from the source of the pebbles increases, the formation becomes more and more a series of fine-grained sandstones and shales, with subordinate grits and conglomerates.

Typical section.—No opportunity to measure a complete section of the Cutler beds has been found, but the various partial sections exposed in

Dolores valley, a few miles below Rico, when combined may serve to illustrate the character of the formation. This combined section is given below. The upper 1,118 feet (numbers 32 to 60) of this section was measured by E. B. Mathews at several places on the northwest side of the river above Priest gulch, while the lower 390 feet (numbers 1 to 31) was measured by Whitman Cross on the north side of Scotch creek, an eastern tributary of the Dolores. The hiatus between the sections, if there be any, is small. The Rico beds occur immediately beneath the Scotch Creek section and the Dolores Triassic beds rest on the uppermost stratum of the exposures near Priest gulch.

Dolores River section of the Cutler formation

Top	Feet
60. Coarse sandstone or grit, cross-bedded, locally conglomeratic, rather purplish in tone	100
59. Calcareous sandstones, sandy shales, often micaceous and fissile, either red or mottled red and green in color	120
58. Grit-conglomerate, of variable texture, forming ledge outcrops	10
57. Fine grained calcareous sandstones, sandy shales, with occasional thin layers of harder sandstones in red or variegated red and green	80
56. Sandy shales, with thin sandstones at intervals; variegated or mottled dark red and light green; have peculiar nodules	55
55. Grit-conglomerate	20
54. Calcareous sandstone or sandy shale	100
53. Grit-conglomerate, very similar to number 60	30
52. Friable sandstone	35
51. Grit-conglomerate, hard and forming a prominent ledge outcrop	15
50. Sandy shales and crumbling sandstone, strong red color, partly calcareous	110
49. Calcareous shales	20
48. Coarse arkose sandstone	30
47. Calcareous shales	30
46. Sandstone variegated	20
45. Calcareous shales	15
44. Coarse sandstone, friable, variegated	15
43. Hard sandstone, with few small pebbles of quartzite	15
42. Dark red sandy shales; in places calcareous and then massive; in other parts micaceous and then fissile	90
41. Compact arkose sandstone, with few pebbles; cross-bedded; friable sandstones near top	15
40. Calcareous clay, or marl, reddish, with spots of various shades	33
39. Friable sandstone, largely quartzitic, variegated in color	15
38. Conglomerate and arkose grit; most conglomeratic in center; a grit with some pebbles in upper and lower portions; pebbles of greenish slates and schists, quartzite, granite, and greenish porphyry	30
37. Calcareous shales, fine-grained, variegated	30
36. Fine-grained, reddish shale	15

Dolores River section of the Cutler formation—Continued

Top	Page
35. Massive sandstone, coarse grained, cross-bedded, streaked with light-colored layers; some shaly partings	15
34. Friable sandstone, purplish and grayish layers alternating irregularly	20
33. Sandstones, finely laminated, compact, cross-bedded, variegated	25
32. Calcareous clay shales, graduating into more massive sandy shales and a rather tough sandstone	10
31. Sandstone, micaceous, red or green, carrying a thin layer of coarse conglomerate near the top	10
30. Arkose sandstone, cross-bedded, white	20
29. Sandstone, micaceous, red and green	6
28. Arkose sandstone, coarse grained, white	7
27. Sandstone, compact, micaceous, salmon color to red	10
26. Calcareous shales, green and brown	5
25. Sandstone, micaceous and compact, containing layers of gnarly limestone from 2 to 12 inches thick	18
24. Calcareous sandstone, generally red, but mottled; contains thin layers of gnarly limestone	15
23. Arkose sandstone, cross-bedded and conglomeratic in part; this layer is purple at the base, and this color alternates with greenish-yellow and red bands; in the upper part a white and cream color prevails	30
22. Sandstone, rather flaggy, containing a layer of gnarly limestone at the base	18
21. Calcareous sandstone, shaly in the lower part and containing gnarly limestone near the top; color, bright red	10
20. Sandstone, micaceous, massive, becoming flaggy at the top, where it contains limestone nodules; color, red	5
19. Calcareous sandstone, containing small limestone nodules near the top; color, red	5
18. Calcareous sandstone and red arkose, containing limestone pebbles; purple and white in the upper part; red below	12
17. Covered	12
16. Arkose sandstone, variegated, red, white, and purple	6
15. Sandstone, micaceous, flaggy	5
14. Arkose sandstone, flaggy, becoming finer grained and micaceous in the upper part; color, pink, with narrow white bands	15
13. Arkose sandstone, somewhat conglomeratic in the upper part, and with thin shaly bands near the center and at the top; color, white and pink, irregular bands	35
12. Sandstone, micaceous, flaggy, very thin bedded at top; color red	10
11. Calcareous sandstone; a few thin layers of nodular limestone; color, red.	7
10. Sandstone, micaceous, flaggy; color, red	6
9. Sandstone, micaceous, flaggy, becoming more compact in upper part	15
8. Arkose sandstone, white, banded with red	7
7. Calcareous sandstone, rather poorly exposed in the upper part, but flaggy and somewhat shaly, becoming more shaly in the lower part, and containing nodules of limestone; color, red	35
6. Arkose sandstone, red above, white below	6

Dolores River section of the Cutler formation—Continued

Top	Feet
5. Shale, probably calcareous; contains nodules of limestone; color, red	5
4. Sandstone, micaceous; color, dark purplish red	5
3. Calcareous sandstone, irregularly nodular and flaggy; contains gray nodules of limestone, but no well defined limestone; color, red	25
2. Arkose sandstone, micaceous, thin conglomeratic, cross-bedded; near the base there is a thin black shale which is quite variable; color, white, with bluish and green zones	15
1. Calcareous sandstone, with a gnarly gray limestone at the top; color, red.	10
Total	1,508

Age of Cutler beds.—The Cutler beds are manifestly the uppermost portion of the Paleozoic section now preserved in southwestern Colorado. Since they rest on beds which contain a fauna intermediate in character between those of the Pennsylvanian and the so-called Permian of the Mississippi valley, though more closely related to the former, it is natural to refer the Cutler provisionally to the Permian series. If it does not belong to the Permian it is transitional (Permo-Pennsylvanian) or belongs to the uppermost Pennsylvanian. Such is the simple reasoning when the relations of the Hermosa and Rico faunas to the eastern Carboniferous are considered. But the question is not so simple when the relations of the Colorado formations to those of the Plateau province are reviewed. The Hermosa and Aubrey faunas are both regarded as Pennsylvanian, but Mr Girty informs us that the Hermosa has no species in common with the typical Aubrey of the Grand Canyon section, as far as known. Mr Girty further states that the lower Aubrey fauna from beds at the junction of the Grand and Green rivers, comprising a large part of the Aubrey fauna described by White in Powell's Uinta report (36), is markedly different from the Aubrey of the Grand canyon, as it also is from the Hermosa fauna of Colorado. These faunal differences must seemingly be explained in one of three ways: (1) By a rapid gradation of forms within a comparatively narrow zone; (2) by the assumption of an effective barrier between the Aubrey and Hermosa seas, extending for hundreds of miles from eastern New Mexico west and northwest across New Mexico and Utah; or (3) by assuming one of the formations to be younger than the other, and that the Pennsylvanian section is incomplete both in Colorado and in the Plateau country. Studies of the fossiliferous Carboniferous about the La Sal mountains, which are in contemplation, should throw light on this subject, and further discussion seems unnecessary at this time.

If the Aubrey and Hermosa are practically equivalent, as the stratigraphic relations suggest, the Cutler beds occupy a position corresponding to that of the Permian of the Kanab valley in Utah and the formation of the Zuni plateau referred to the Permian by Dutton, as will be brought out in the discussion of correlation.

Dolores formation.—General characterization.—The Dolores formation embraces the Triassic portion of the Red beds of southwestern Colorado, several hundred feet in thickness. It is limited, both above and below, by planes of unconformity. In most places it rests on the Cutler formation and is overlain by the La Plata sandstone. It consists of sandstones, shales, and fine-grained conglomerates, all more or less calcareous. There are two divisions of the formation: the lower embraces variable sandstones, conglomerates, and shales, partly greenish or gray in color and persistently fossiliferous at several horizons; the upper portion is a very fine and evenly-grained sandstone and shale of strong red color.

Lower fossiliferous portion.—The lower portion of the Dolores formation consists of an alternation of reddish sandstones, more or less shaly, with conglomerate, consisting chiefly of very small limestone pebbles. These conglomerates characterize several bands within the lower 300 or 400 feet of the Dolores, and, owing to their fossil content and notable lithologic characteristics, these beds are the most diagnostic of the whole formation. The conglomerate beds are very variable in number. In some places a ledge 20 feet thick may be seen to consist chiefly of conglomerate with numerous sandy partings and common cross-bedding. A few yards distant the same strata may be composed chiefly of sandstone with a number of thin layers of conglomerate.

Some of the conglomerate bands are more persistent than others, but it is probable that no stratum of the conglomerate is continuous for any great distance. The limestone of the pebbles in the conglomerate is usually very fine grained, and does not appear to have been derived from the older limestones of the Hermosa formation, since no fossil-bearing pebbles have been found. The pebbles are commonly very small, and sometimes they are of such minute, shot-like appearance as to suggest that they are pisolitic. Pebbles several inches in diameter are sometimes found, and these are usually unsymmetrical. It is believed the conglomerate is, at least partially, derived from the breaking up of limestone deposits of the Dolores sedimentation.

The conglomerates are commonly associated with thin bedded gray sandstones or greenish-gray sandy shales. A complex of such alternating strata 50 to 75 feet in thickness can be traced for long distances on the flanks of the San Juan mountains. Carbonaceous material is common in the shaly beds, but determinable leaves have not been observed. The lowest stratum of the Dolores is generally more or less conglomeratic, and in some localities is a harder stratum, forming distinct ledge outcrops. The thickness of the lower division of the Dolores seems to vary considerably, increasing from the mountains west and southwest toward the Plateau country.

Upper red sandstone member.—The upper member of the Dolores is commonly a very even, fine grained, reddish sandstone, free from conglomerate, but variably shaly in different places. The shales are, however, always very sandy and there are seldom pronounced division planes of great lateral extent. The bands of parallel, massive sandstone are often 20 feet or more in thickness. The material is mainly quartz sand, with a calcareous cement. In color this upper sandstone is usually bright brick-red or vermilion, shading sometimes into purplish above and a duller, darker red below. In texture this red sandstone is very much like the overlying La Plata sandstone, and where the latter is highly colored the two formations seem sometimes inseparable, but the La Plata is commonly orange or yellow in color when it departs from the normal gray or white.

The upper member of the Dolores is absent in the Ouray and parts of the Telluride quadrangles, but presents an increasing thickness southward through the Rico and La Plata quadrangles. Nearly 500 feet of quite uniform sandstones were observed on the eastern flanks of the La Platas. The variation in thickness and the disappearance of the red sandstones to the north is due chiefly to the post-Dolores erosion.

Fossils.—The limestone conglomerates of the lower Dolores contain scanty but very widely distributed fragments of bones and teeth belonging to vertebrate animals. Much less frequently invertebrate and plant remains of identifiable character occur in the same strata. The vertebrate remains have never been found as connected skeletons, or even closely associated bones belonging to one individual. They are usually worn and often broken. The most common fossils are the teeth of crocodiles and dinosaurs. Material collected from many localities has been studied by F. A. Lucas. The greater number of the remains belong to the belodont crocodiles, while less numerous are those belonging to a megalosauroid dinosaur, perhaps *Palæoctonus* of Cope. It is probable that the belodont remains belong to the genus described by Lucas (28) under the name *Heterodontosuchus ganei*, or to allied forms. Poorly preserved outlines of *Unio* have been seen in several places and a small gasteropod shell has been found in the Rico and La Plata quadrangles. According to Stanton, the latter belongs to the genus *Viviparus* or to a closely allied form.

The fossils first announced by Hills (20) from the Dolores beds were found in the Telluride quadrangle, on the north side of the San Miguel river, 1½ miles below the present site of the town of Telluride. Apparently, the locality is unique in the number and comparatively excellent state opreservation of the remains found. These fossils were submitted to experts for determination, but unfortunately they were lost before being fully identified. Mr Hills regarded the abundant teeth found in one stratum as belonging to a crocodile near *Belodon priscus*, and certain fish remains as representing a ganoid similar to *Catopterus gracilis*. A small gasteropod shell and eleven or twelve apparently determinable species of plants were found. The Belodon and Catopterous remains were found in the limestone conglomerate, occurring here about 50 feet below the La Plata sandstone, and the fossil leaves in thin bedded, reddish, micaceous sandstones not far below the conglomerate.

La Plata formation.—The strata of assumed Jurassic age occurring below the Dakota Cretaceous in the Elk mountains of central western Colorado were grouped together and called the Gunnison formation by Eldridge in the Anthracite-Crested Butte folio. The formation is described by Eldridge in these terms:

> "At its base is a heavy white quartzite, 50 to 100 feet thick, usually in a single bed. Above it, in some cases succeeded by other sandstone layers, is a blue limestone containing abundant fresh-water shells of the genera *Limnea*, *Valvata*, and *Cypris*. The remainder of the formation consists of gray, drab, pink and purple clays and marls, through which run thin intermittent beds of drab limestone."

In the San Juan region and the adjacent country it is desirable to subdivide the Gunnison, grouping the two lower sandstones with the intervening limestone and associated shales as the La Plata formation, and the upper marls, clays, and sandstones as the McElmo formation. This has been done in the Telluride and La Plata folios (3 and 4).

The La Plata sandstones are commonly not indurated as in the Elk mountains; instead they are rather friable and crumbling, although of homogeneous texture. Cross-bedding is a marked feature, and not infrequently a massive ledge as much as 100 feet in thickness has no prominent division planes.

Of the two sandstone members the lower is commonly thicker and much more massive than the upper. The latter is in fact occasionally thin bedded and shaly and may be inconspicuous.

The calcareous member is very variable in character. On the San Miguel river, in the Telluride quadrangle, it is in some places a pure massive, blue-gray limestone in several beds and with almost no shale. Usually dark calcareous and bituminous shales and thin bedded sandstones, with more or less of massive limestone, occur between the two main sandstones and sometimes reach a thickness of nearly 100 feet.

The total thickness of the La Plata formation varies, in the area we have examined, from about 100 feet in the Ouray and Telluride quadrangles to 500 or more in the La Plata mountains, and it is known that to the west all members increase still further in thickness.

The sandstones are almost wholly quartzose, and their normal color adjacent to the San Juan mountains is white or gray. But in several localities the lower sandstone is more or less strongly orange or yellowish in color, and even red tints have been observed. This coloration is most pronounced to the west of the San Juan, in the Dolores valley. The possibility that the La Plata may be of strong red or orange color is the principal ground for bringing the formation into the present discussion.

The McElmo formation.—This formation includes the upper part of the Gunnison formation of Eldridge, described by him as consisting of variously colored clays and marls with subordinaate limestone. About the San Juan mountains sandstones or sandy shales become prominent, although the marls are everywhere a very characteristic feature. Eldridge pointed out that the Gunnison beds seemed lithologically and stratigraphically equivalent to the Morrison formation of the eastern border of the mountains. The discovery by Riggs (37) of vertebrate remains of Morrison types in the Grand River valley indicates clearly that certain portions of the McElmo and Morrison are to be correlated, but that the formations are coextensive remains to be proven.

The McElmo beds range from 300 to 900 feet in thickness in different parts of the San Juan area. Where thickest, they consist largely of sandstone. The formation is ordinarily not highly colored except in its marl and clay strata, but in certain localities the sandstones are dull red.

PART II. CORRELATION OF THE FORMATIONS

INTRODUCTION

The Red beds of the Rocky Mountain province have proved to be perhaps the most difficult portion of the Paleozoic and Mesozoic section to analyze and reduce to definite groups and formations. In the first place, the red color has been found unreliable as a guide in correlation. It extends at some places into the fossiliferous Pennsylvanian rocks and may penetrate upward into Jurassic beds. Fossils have been discovered in Red bed strata in many different localities—here of Permian, there of Triassic affinities. Unfortunately the two kinds of fossil evidence have seldom been found in one section, affording a means of division. Triassic fossils occur in some places very near the top of the Red beds and in others near their base, in proximity to known Pennsylvanian strata. This apparent range of Triassic fossils has been a prominent factor in forming what seems to be the general opinion that the larger part of the Red beds is to be assigned to the Trias.

As far as I know, no one has presented evidence of a stratigraphic break within the Red beds or suggested that the conflicting evidence as to age might be explained by such a break. The Ouray unconformity, however, establishes for southwestern Colorado a definite line between Triassic and pre-Triassic portions of the Red beds, which can be traced on a lithologic basis where no visible unconformity exists. From evidence which will be presented in following pages it seems certain that the Dolores formation may be positively recognized through its fossils and lithologic character in Utah and Arizona and very possibly in New Mexico. As a step toward a better understanding of the Red beds, I desire to make certain suggestions as to the correlation of the Cutler and Dolores formations with strata in other parts of Colorado, in Wyoming, and particularly in the Plateau province of Utah, Arizona, and New Mexico. The discussion is based on a study of the literature, on recent published discoveries and on unpublished information. Naturally much of the correlation suggested is tentative.

Four principal factors have had influence in this tentative correlation:

a. The lithologic character of formations compared.—This is the most important on the whole, since it is the only one applicable in all places.

b. Fossil evidence.—This guide is becoming more and more important as new discoveries are made. Unfortunately, collectors of fossils, and even paleontologists are not always alive to the importance of careful stratigraphic studies and accurate measurement and description of sections in the localities where fossils are obtained. Their work is therefore often shorn of much of the value that should attach to it.

c. The influence of post-Triassic elevation and erosion.—The stratigraphic break at the base of the La Plata sandstone is one of great magnitude throughout the western portion of Colorado. In several places the La Plata is seen in angular unconformity with the entire Paleozoic and older Mesozoic section. It is possible that synchronous elevation, in gentle folds or low domes, occurred in the Plateau district, but have not been recognized.

d. The influence of the pre-Triassic elevation and erosion.—While it appears probable that the pre-Dolores uplift was by no means so extensive as the post-Dolores disturbance, it is plain that its influence must be looked for in the Plateau country as well as in the Rocky mountains.

RELATIONS OF COLORADO FORMATIONS TO THOSE OF THE PLATEAU PROVINCE

The Red beds and adjacent formations have been described in foregoing pages in the development they possess on the eastern side of the zone between the geologic provinces of the Rocky mountains and of the Plateau country. Even in the small area studied in detail these formations illustrate the general principle that in the mountain belt of repeated disturbances, of rapid erosion, of land areas, and shore lines, the stratigraphic section will exhibit much greater variation in composition and thickness of its members than in the adjacent region, which has been one prevailingly of deposition.

The general conditions under which correlation of the San Juan formations with those of the Plateau section must be made are as follows: Adjacent to the mountains there is a broad zone of gentle westward slope in which Cretaceous beds occur. The main streams flowing west and south cut valleys into and in some places through the Cretaceous into underlying formations. Nearer the canyon of the Colorado the valleys widen and broad platforms and terraces of Jurassic and Triassic beds appear, the Cretaceous being restricted to the divides and isolated mesas. The Paleozoic formations appear at first only in isolated exposures in the deeper canyons, but far to the southwest rise to form the broad plain called the Colorado plateau, on the south side of the Grand canyon. Thus the older the formation the greater are the gaps between districts of good exposures, and the greater the likelihood that in the covered tracts unsuspected complications have entered into the problem.

The discussion following will first take up the evidence afforded by recent observations in certain districts and later consider the correlation from a more general standpoint.

FORMATIONS OF DOLORES VALLEY AND UNCOMPAHGRE PLATEAU

The region in general.—It is natural to begin this discussion of correlation with a consideration of the formations occurring in the Uncompahgre plateau and the bounding valleys of the Dolores and Grand rivers, a district traversed by A. C. Peale, of the Hayden Survey, in 1875 (35). The heart of the plateau is about 80 miles northwest of Ouray, and Cretaceous formations occupy the greater part of the intervening country. The San Miguel river, however, affords a section extending somewhat below the Dakota sandstone for the entire distance from the Telluride quadrangle to its union with the Dolores river, and the Dolores itself penetrates locally through Jurassic and Triassic into Carboniferous formations.

Observations of A. C. Spencer.—In 1899 Dr A. C. Spencer, who had been my assistant in western San Juan work for 3 years, made a reconnaissance trip to Paradox and Sinbad valleys, which are tributary to the Dolores. His route of travel was from Placerville, on the San Miguel river, following down that stream for some 15 miles, and thence across to the East Paradox valley. This route allowed Spencer to trace the Dakota, McElmo, and La Plata formations from the Telluride quadrangle to the lower Dolores valley, with but two gaps of a few miles each for the two formations below the Dakota. The following general statement of Spencer's observations is made with his permission.

The La Plata formation was found to increase in the thickness of its sandstone members going down the San Miguel valley, while the calcareous medial member disappears as such, but seems to be replaced by sandstones of thin bedding. In Paradox valley the La Plata formation has three parts. The upper is 400 to 450 feet in thickness, white in its upper portion, and stained red or orange below. It is mainly massive, but is often friable and crumbling in its lower portion.

The middle member is reddish sandstone, shaly at the top with a few chert bands. Thickness, 250 feet.

The lower sandstone is from 300 to 350 feet thick, of the typical massive and cross-bedded texture common in this part of the formation. In some places this sandstone is white, but it is more frequently reddish or orange-colored through weathering, while nearly white within. The La Plata thus becomes a formation of about 1,000 feet in thickness, and its massive portions form abrupt cliffs of red, orange, yellow, gray, or white colors in different places.

Above the La Plata Spencer found the McElmo formation to be about 500 feet in thickness, with variable relations of sandstone and shale. It has a decided red color locally.

Below the La Plata, distinguished by Spencer, there occurs a much deeper red sandstone formation, vermilion or brick-red in hue, and corresponding to the upper division of the Dolores as it has been described in this paper. Apparently the lower part, characterized near the San Juan mountains by the variable strata carrying fossiliferous limestone conglomerate, is not, on the Dolores, markedly different from the upper in texture or color. Spencer found limestone conglomerate rich in bone fragments in several places, and on La Sal creek this horizon was but about 100 feet below the La Plata sandstone. The total thickness of the nearly uniform Dolores formation is about 1,000 feet in the neighborhood of Sinbad valley, while much less in other localities.

Below the Dolores beds Spencer found coarser Red beds, often conglomeratic, with pebbles 3 inches or more in diameter, and several hundred feet of such strata were noted. No opportunity was found to measure a section showing the full thickness of these coarser Red beds, but, as observed by Peale, they are underlain by fossiliferous Pennsylvanian Carboniferous in Sinbad valley, where there is also much structural complexity obscuring the relations.

Spencer's observations seem to show that the section of the lower Dolores valley embraces strata to be correlated with the Cutler, Dolores, La Plata, and McElmo formations of the San Juan region.

Comparison with Peale's section.—The Hayden map of the Uncompahgre Plateau distinguishes "Upper Carboniferous," Trias, Jura, "Lower Dakota," and "Upper Dakota" as the cartographic units of the sedimentary section. The "Upper Dakota" is clearly the Dakota as commonly defined. The "Lower Dakota" embraces a group of strata approximately, or perhaps closely, corresponding to the McElmo, and the "Jura" must include the upper part of the La Plata with, perhaps, the lower part of the McElmo. The "Trias" is represented by the map as the main formation of the region and as resting throughout the Plateau on granite, gneiss, or schist. Near the Dolores the Carboniferous rocks intervene.

According to the descriptions of Peale, this Triassic formation clearly embraces the greater part of the strata referred by Spencer to the La Plata formation and at least the upper part of the Dolores. His general description is as follows (35, page 80):

> "A massive yellow, white, or pink sandstone forms the top of the series. Toward the western part of our district (i. e., the area under discussion) this sandstone is calcareous. In many places the sandstones are markedly cross-stratified. The color is subject to much change locally, passing from white, through orange and pink, into deep red. Below the massive sandstone are blood-red shales, followed in most places by massive brick-red sandstone."

This description seems obviously to apply to a section embracing the lower La Plata and upper Dolores beds.

Below the Triassic of Peale occur "shales and blood-red sandstones, which on the Dolores, change gradually into gypsiferous shales and sandstones. The latter, I have considered as belonging to the Permian. It is difficult to draw any line between the Trias and Permian, and I have been obliged to do so arbitrarily." (35, page 80.)

The strata referred to by Peale as probably Permian are called "Upper Carboniferous" on the published map. It is apparent that the Cutler formation, if present in the lower Dolores valley, must embrace the beds called Permian in Peale's report.

In view of the fact that an examination of the Uncompahgre plateau during the coming season is contemplated, it seems undesirable to suggest at the present time any further correlation. It was Peale's belief that the absence of the Carboniferous and the varying thickness of Mesozoic beds between the gneisses and the Dakota Cretaceous in the Uncompahgre plateau and the adjacent Gunnison valley to the east was evidence of an island never covered by sediments until the Dakota epoch. It seems probable, however, that the erosion of the pre-Dolores interval removed the Paleozoic beds, and that the pre-La Plata erosion in turn removed some, if not all, of the Dolores strata in this district. Peale's overlap may prove to be wholly explainable in this way. Faulting and folding, presumably of several epochs, undoubtedly adds much to the complexity of the relations.

Newberry's section.—The Red beds of the Grand River valley and canyon, for some distance below the mouth of the Dolores, may be assumed to correspond in general to the development possessed in the Dolores valley. It is only from 25 to 50 miles west from Paradox valley to the region where Newberry made, in 1859, a section in the "Canyon Colorado," which enters Grand river from the east a few miles above its junction with Green river. In Newberry's often cited "Generalized section of the valley of the Colorado" (33, page 99) (in which it should be noted he does not refer to the "Rio Colorado Grande," as the Colorado river is termed on his map) some 1,726 feet of beds are referred to the Trias. Below this section some fossiliferous Carboniferous (Pennsylvanian) strata and above them Jurassic beds with large saurian bones and fossil wood, which latter undoubtedly belong to the McElmo formation.

It seems to me that the three upper divisions of Newberry's Trias, aggregating 970 feet in thickness, belong to the Jurassic, and possibly represent the three divisions of the La Plata formation, corresponding to those occurring in the Dolores valley. Nothing appears in Newberry's section which can be definitely correlated with the "saurian conglomerate" zone of the Dolores formation, but the suspicion may be entertained that the equivalent of the latter is described in number 11 of his section, embracing 92 feet of "greenish-gray micaceous conglomerate and gray sandstone, separated by red or purple shales." If this is correct, there are 514 feet of red sandstones below, which may represent the Cutler formation.

FORMATIONS OF THE LOWER SAN JUAN VALLEY

In general.—From the summits of the La Plata or Rico mountains one may look westward far out over the plain, the monotony of which is relieved here and there by isolated mesas, remnants of older plateaus. In the early morning or near sunset one can often get a glimpse of the precipitous scarps and the gigantic towers and pinnacles of San Juan valley, 100 miles away, which stand out with a rosy gleam or in contrasting dark shadow, and give a faint suggestion of the wonderland lying just beyond the limit of vision. Going toward this distant valley of remarkable erosional forms one passes over the plain called the Montezuma valley, underlain by the Dakota sandstone, and at about 25 miles from the La Plata slopes enters the drainage of McElmo creek. This stream unites with the San Juan river where it turns westward to the Colorado after its long detour in New Mexico and Arizona. The canyons of the various branches of the McElmo are cut in the Jurassic beds and the name has been given to the upper formation described in preceding pages. Huge fossil bones are commonly reported to occur in these beds and they are supposed to represent the saurian fauna elsewhere known in these strata.

The San Juan valley was partially explored by Holmes (23) and Newberry (33), but there is little profit in trying to recognize the Dolores and Cutler formations in the sections they refer more or less provisionally to the Trias. No fossil-bearing horizon corresponding to the Dolores "saurian conglomerate" was observed by these explorers, although both correlate certain beds with the horizon at which Newberry obtained dinosaur remains farther north, and both refer to this bed as "Triassic (?)" (23, general section, page 244); (33, page 105). In his generalized section Newberry himself calls this fossil-bearing horizon "Jurassic (?)," a reference which seems more reasonable.

Observations by H. S. Gane.—Important evidence as to the formations of the San Juan valley in Utah has been secured by Dr Henry S. Gane, who in 1897 went from Mancos, Colorado, to the canyon of the Colorado, passing down the San Juan valley on its northern side. Doctor Gane had been my assistant in the Geological Survey during the study of the Telluride and La Plata quadrangles, and was thus well equipped to make correlation studies in the Plateau district. With his permission, I make certain statements of his observations.

In the San Juan valley the La Plata formation is stated by Gane to have a general development similar to that which it possesses in the lower Dolores valley, according to Spencer. It thickens greatly and its upper and lower sandstone members are very massive, and exhibit red, orange, and yellow colors, though they are often white or gray. The great cliffs and remarkable towers and pinnacles of the valley are mainly caused by the massive La Plata sandstones, and not by Triassic Red beds, as assumed by Holmes and Newberry. Opposite the "Water Pocket fold" the canyon of the Colorado is, according to Gane, mainly cut in the La Plata beds, 1,000 feet or more deep.

That Gane's correlation is correct, as to the La Plata, is indicated by the presence of the Dolores formation with its fossiliferous limestone-conglomerates below the La Plata. In this conglomerate Gane obtained a large portion of a crocodile jaw, at Clay hill, some 20 miles east of the Colorado and 10 miles north of the San Juan river. This specimen has been described by F. A. Lucas as representing a new form called by him *Heterodontosuchus ganei* and stated to have marked Triassic affinities (28). It is one of the belodonts, and teeth of these animals are perhaps the most common fossil throughout the limestone conglomerates of the Dolores. Lucas identifies the same species in the Trias of Arizona, as will be brought out later on.

Limestone conglomerate was found by Gane widely distributed in the San Juan valley, carrying saurian and crocodilean teeth and bone fragments, fossil wood, and ill-preserved shells of Unio. He made no measurement of the thickness of the Trias and had no opportunity to study the underlying formation.

While Gane observed no unconformity between the Dolores and La Plata formations, it is noteworthy that the fossiliferous beds of the Dolores occur near the top of the formation, and that there is here, apparently, no massive, vermilion-colored sandstone, like that which is the normal upper member. It is not improbable that this sandstone was largely or wholly eroded before the La Plata deposition.

THE ZUNI PLATEAU, NEW MEXICO

The development of the Triassic and Jurassic formations to the south from the Colorado area can not be traced so satisfactorily as to the west in the Dolores and San Juan valleys.

For more than 100 miles south from the La Plata mountains the Red beds and the overlying Jurassic formations are concealed by Cretaceous strata. They reappear, however, in the Zuni plateau, on the western border of New Mexico, and form the surface of a large part of eastern Arizona, both regions being within the Plateau province.

Newberry traversed this district with the Ives expedition in 1858, and in his report distinguished two groups of strata between the fossiliferous Carboniferous (Pennsylvanian) and the Cretaceous, namely, a lower group variably designated as the "Red sandstones," "Saliferous sandstones," or the "Salt group," and the overlying "variegated marls" (33). This simple division Newberry applies all the way from the Little Colorado to Santa Fe, remarking repeatedly that he sees no reason for further subdivision.

A much more instructive analysis and description of the section of the Zuni plateau was given by Dutton in 1886 (10). He refers the "variegated marls" of Newberry to the "Jurassic" and calls them the "Zuni sandstones." The "Saliferous sandstones" of Newberry's report Dutton divides into three formations. At the base is a formation 450 feet thick, mainly "sandy shales, containing gypsum and selenite in abundance, with here and there thin bands of limestone." At some unspecified horizon in this formation Dutton found "several specimens of *Bakewellia* and an attenuated form of *Myalina*." On this ground he correlates these beds with the Permian of the Kanab Canyon district, where Walcott had discovered a more extensive fauna. "The Permian beds are distinguished for their dense and highly variegated colors—chocolate, maroon, dark brownish reds alternating with pale, ashy gray, or lavender colors" (10).

The Permian strata thus described are overlain by "a very coarse, almost conglomeratic sandstone," some 50 feet in thickness, which Dutton correlates unhesitatingly with the "Shinarump conglomerate" (a particular conglomerate within the Shinarump group), referring to the fact that it is persistent and uniform in aspect wherever it appears throughout the plateau country of Utah and Arizona. He does not further describe it in this report.

Following Walcott, the conglomerate thus identified as the Shinarump in the Zuni plateau is considered by Dutton as the basal stratum of the Trias. Above it occur some 1,600 feet of "sandy shales," also referred to the "Lower Trias." The lower 650 feet of these beds are almost exactly like the Permian below, while the upper portion is of lighter color.

Succeeding the "Lower Trias" shales comes the "Wingate sandstone" formation, 450 feet in thickness and bright red in color. Dutton describes it as "in reality a group or subgroup of sandstone in which the lines of bedding are generally, but not always, effaced. Sometimes, however, the partings are almost obliterated, so that the edge of the entire subgroup is presented as a single indivisible member. Sometimes a portion of the partings is effaced, and a part is so presented. Sometimes partings are seen to divide the whole of it into a series of beds varying in thickness from a yard or two to 20 feet. Most frequently there will be at least 250 feet presented without subdivision, as a vertical wall." Of importance to the present discussion is the apparent absence of cross-bedding. As to correlation, Dutton says:

> "This formation is without much doubt the equivalent of the Vermilion Cliff series in southern Utah," where it attains a thickness of more than 1,000 feet. He also remarks that "out of it have been carved the most striking and typical features of those marvelous plateau landscapes, which will be subjects of wonder and delight to all coming generations of men. The most superb canyons of the neighboring region, the Canyon de Chelly and the del Muerto, the lofty pinnacles and towers of the San Juan country, the finest walls in the great upper chasms of the Colorado, are the vertical edges of this red sandstone."

Above the Wingate sandstone comes the formation generally characterized by Newberry as the "variegated marls," but described by Dutton as prevailingly arenaceous and named the "*Zuni sandstones.*" This formation is 800 to 1,300 feet in thickness.

> "It is wonderfully banded and variegated in color. Many pages might be written descriptive of the changes of color which it presents, not only as between different beds in the same section, but as between the same beds in different sections."

In some places the bedding is inconspicuous and several hundred feet of sandstone may appear as one unit of massive rock. Cross-bedding is often very pronounced, as in the striking remnant of erosion called the "Navajo church." The lower portion is the more massive, the upper part more friable, and gypsiferous shales are common in the latter. Above the Zuni sandstones comes the Cretaceous section, beginning with the undoubted equivalent of the Dakota.

Comparing the formations of the Zuni plateau, as described by Dutton, with those of southwestern Colorado, it seems probable that the Zuni sandstones represent the Gunnison group. Dutton's section is not sufficienly detailed to permit a suggestion as to the exact equivalents of the La Plata and McElmo formations, but it is difficult for me to suppose that the Navajo church is constituted of anything but one of the La Plata sandstone members.

The Wingate sandstone corresponds in position and character to the upper, vermilion-colored sandstone of the Dolores formation. The absence or subordination of cross-bedding and the constancy of the red color both tend to support such a correlation. If the Wingate is upper Dolores, it would appear probable that the "lower Triassic" of Dutton is at least approximately the equivalent of the lower Dolores, and it may well be that the basal conglomerate called the Shinarump by Dutton is actually the same as the basal conglomerate of the Dolores. Dutton does not speak of limestone conglomerates in the Trias, nor did he find fossil remains in it, except the abundant fossil wood.

If the Wingate sandstone belongs to the Dolores, Dutton was probably wrong in saying that the striking towers and pinnacles of the lower San Juan valley are made of that sandstone, for the observations of Gane indicate that the lower La Plata sandstone is the one producing the prominent erosion forms of the San Juan, being there of pronounced red color.

Beneath the Trias in the Zuni district is Dutton's Permian, lithologically a typical Red bed formation. That would correspond to the Cutler formation in stratigraphic position; but other factors enter into the problem at this point and render any definite suggestion of such a correlation premature. Below the Zuni Permian comes the Aubrey group, and beneath the Cutler occurs the Hermosa formation (ignoring the uncertain Rico beds), both Aubrey and Hermosa carrying Pennsylvanian invertebrate faunas. Dr G. H. Girty informs me, however, that these faunas are not known to have a single species in common, and the equivalence of the two fossiliferous formations is therefore by no means to be assumed, though their stratigraphic position seems to be the same. It is hoped that data bearing on this question may be obtained in the near future, and further discussion is therefore postponed. Dutton's description of the Permian and Aubrey formations shows that the term Red beds applies to them.

NORTHEASTERN ARIZONA

From the Zuni plateau a wide tract of upland stretches for 150 miles or more northwest to the brink of the Colorado canyon. On the northeast is the San Juan valley and on the southwest is the Little Colorado. It is the land of the Moqui and the Navajo Indians. Beneath the Eocene and Cretaceous strata of the higher central plateau appear the Jurassic and Triassic beds, the character of which on the San Juan side has already been considered. That the same systems are represented continuously from the Little Colorado to the Zuni plateau was long ago ascertained by Newberry (32), though definite evidence of the Triassic age of any particular strata has been but recently brought to light.

In 1899 Lester F. Ward explored the celebrated "Petrified Forest" of Arizona, which occurs on the northeast side of the Little Colorado, in the Triassic beds (42). The fossil wood collected by Ward has not been described, but in association with the wood he discovered fragmentary vertebrate remains, of which F. A. Lucas announced the general character in a preliminary note (29). Subsequently further collections were made by Barnum Brown for the United States National Museum, and a part of the fauna has been described by Lucas (30).

The greater part of the material found by both Ward and Brown is referred by Lucas to two belodont crocodiles, one being the species described by him as *Heterodontosuchus ganei*, the type of which was found by Gane in the Dolores beds of the San Juan valley; the other called *Episcoposaurus* Cope. Associated with these remains were found bones of three other vertebrates. One of these, a large labyrinthodont amphibian, is described as *Metoposaurus fraasi*, n. sp., the generic identity having been concurred in by Dr E. Fraas, the authority on Triassic vertebrates of Europe. Another form is described as *Placerias hesternus*, a Cotylosaurian, both genus and species being new. Still other remains are referred by Lucas to the dinosaur *Palæoctonus* Cope.

After referring to the discovery of a similar vertebrate fauna near Lander, Wyoming, which will be discussed on a later page of this paper, Lucas states:

> "Aside from the interest attached to the finding of this new species is the more important fact, pointed out by Doctor Fraas, that the genus *Metoposaurus* is characteristic of the Keuper of Europe, and that we have in these Triassic beds of Arizona, Utah, and Wyoming the same combination of belodont and labyrinthodont as in the Keuper" (30).

It is now manifestly important to determine the stratigraphic relations of the horizon or zone in which this well marked vertebrate fauna occurs, and upon this point Ward (42) made very valuable studies, although it is still difficult to correlate his data with the more general statements of earlier observers concerning other localities.

The vertebrate fauna discovered by Ward occurs near the middle of a section some 3,500 feet in thickness, all of which is assigned to the Trias. Ward divides this section into three parts. At the base are the "Moencopie beds," 700 feet in thickness, consisting chiefly of dark reddish-brown, soft, laminated argillaceous shales, nearly destitute of silica [quartz], highly charged with salt and gypsum." Some calcareous beds grade into white impure limestone. No fossils were found in the Moencopie beds, and Ward states that "the whole series, wherever the contact can be found, always rests in marked unconformity upon the underlying Paleozoic rock (Upper Aubrey)." Upon these facts and the observed transition into overlying Shinarump beds, Ward argues that the Moencopie beds are not upper Paleozoic, as believed by "certain geologists" not named. This seems to mean that they can not, in his opinion, be considered equivalent to the fossiliferous "Permian beds" found by Walcott in Kanab valley, or to the "Permian" of the Zuni plateau.

Succeeding the Moencopie come 1,600 feet of variable strata called by Ward the Shinarump. Within this he distinguishes 2 formations, each 800 feet thick, the lower being the "Shinarump conglomerate" and the upper the "Le Roux beds."

The Shinarump conglomerate of Ward is by no means all conglomeratic. His concise characterization is as follows: "Conglomerates and coarse, cross-bedded sandstones, with clay lenses interstratified with gray argillaceous shales and variegated marls."

In fact, the marls become locally most prominent in zones which are elsewhere strongly conglomeratic.

The Le Roux beds are principally variegated marls, argillaceous and calcareous, followed upward by sandstone, limestone, with flint fragments, and at the top more calcareous marls.

Fossil wood occurs all through the Shinarump group and none is found beyond it. The petrified forests occur within the Le Roux beds and the vertebrate remains were only found in these strata. Bones and fossil wood were found together in many places.

The "Painted Desert beds" of Ward follow the Le Roux beds and consist of sandstones. The lowest stratum, 100 feet thick, is soft, friable, highly argillaceous, and of orange color. Above this come 800 feet of variegated sandstones, regularly stratified and brilliantly colored. Brown, cross-bedded sandstones (200 feet) and white massive sandstones (100 feet) form the top of the section studied.

No doubt the Shinarump group of Ward is in large degree equivalent to the Shinarump of Powell, Dutton, and others, as developed in the Plateau country of Utah, and the vertebrate fauna of the Le Roux beds serves to correlate them with the lower Dolores strata containing the same fauna; but, until the unconformity reported by Ward at the base of the Moencopie beds has been traced sufficiently to demonstrate the importance of the stratigraphic break it indicates, further correlation of the Moencopie strata is difficult. It is reasonable to suppose that the base of the Moencopie is actually the base of the Triassic section, and that deposition began in Arizona much earlier than in southwestern Colorado. On the other hand, it may be that the belodont fauna will be found at horizons lower than the base of the Le Roux beds. If the Moencopie beds are Triassic the stratigraphic break below them accounts for the absence of strata equivalent to the Permian of Kanab valley found by Walcott and to be referred to in the next section of this discussion.

The lower 900 feet of the Painted Desert beds of Ward may plausibly be referred to the Vermilion Cliff, or upper Dolores sandstone, while the brown and white sandstones above probably represent a part of the White Cliff, or the La Plata sandstone.

THE PLATEAU SECTION OF SOUTHERN UTAH

Sections of other investigators.—Having practically traced the Red beds and overlying formations of the Jura from the San Juan mountains to the Grand and Colorado rivers and having tentatively correlated them with formations of the Zuni plateau and the Little Colorado valley, we will now cross the Grand canyon and compare the original sections of the Plateau country, described by Powell, Gilbert, and Dutton, with those which have been studied more in detail in outlying portions of this great stratigraphic province.

Divisions established by Powell.—The formations with which we are now dealing occur in most wonderful development as the steps between the Tertiary high plateaus and the Carboniferous plain through which the Grand canyon has been cut. This succession of terraces and bounding cliffs, often compared to an open book of geological history, exhibit the major divisions of the stratigraphic section in such perfection that Powell naturally drew upon the descriptive terms of this region for the names he was the first to confer. Powell called one great group of strata "the Shinarump," the name meaning "the weapons of Shinav," the wolf-god, and referring to the huge petrified tree trunks which are so common in the formation. To the succeeding divisions the terms "Vermilion Cliff" and "White Cliff" were given from the great scarps which face the Grand canyon and can be traced for hundreds of miles with scarcely a break. These terms are also used by Gilbert and Dutton, save that they substitute the name Gray Cliff for White Cliff.

The reconnaissance explorers of this vast labyrinth of canyon, scarp, and terrace necessarily strove to grasp first the major elements of the problems before them, and it seems clear that in their broader correlations they were in the main correct. The great cliff-makers, the Vermilion and the White Cliff or Gray Cliff sandstones, are traced by Powell to northern Utah and the adjacent portion of Colorado (36), and by Dutton across the Grand canyon to the Echo cliffs above the section examined by Ward. But eastward, toward the San Juan mountains, the change in character of these sandstones caused Dutton to hesitate. He indeed says distinctly that "the Jurassic White sandstone (White Cliff) seems to be peculiar to the northern and western portions of the Plateau province. In southern Colorado and western New Mexico no stratigraphic member has yet been found which can be identified with it" (8). But this positive statement is at once followed by the suggestion, now known to be correct, that through a thinning and assumption of red color, the Jurassic in this eastern district may be wrongly assigned to the Triassic, together with the also diminished Vermilion cliff (8). It seems peculiar, however, that in the report on the Zuni plateau (10) Dutton did not recognize that the white cross-bedded strata of the Navajo church might be the representative of the White Cliff sandstone. It will be recalled that he did correlate the underlying Wingate sandstone with the Vermilion cliff.

The great cliff-forming sandstones of the Plateau province are of similar texture and not yet greatly indurated. They seem to grade one into the other at many points, and the line between them is generally arbitrary as drawn by Powell, Dutton, and others. Powell, indeed, includes the White Cliff in the Triassic because of the apparent transition below and the sharp line above, where a limestone bearing a marine Jurassic fauna appears. But this seeming gradation also appears in Colorado, where it is perfectly plain that a part of the Dolores sandstone has been removed, and near localities where the magnitude of the stratigraphic break between these formations is very evident. The soft Dolores sandstones were no doubt broken up and redeposited, forming a large part of the lowest La Plata beds and causing the apparent transition.

Observations by C. D. Walcott.—The general observations of Powell, Dutton, and Gilbert concerning the Plateau formations were supplemented by Walcott in 1879 through detailed studies of the excellent section displayed in the Kanab valley, and again in 1882 by special examination of the Paleozoic formations. A portion of the results obtained respecting the Paleozoic section and certain structural features have been published. Of special interest to the present discussion are the discovery of Permian fossils and of an unconformity between the Permian and the Triassic beds. In his published section of the Paleozoic formations Walcott (39) refers to the Permian some 855 feet of reddish brown, chocolate, lavender or drab, gypsiferous and arenaceous shales and marls, with impure fossiliferous limestone. There are two divisions with erosional unconformities above and below each one. The unconformity above the Permian is the most important and has been specially described (40). While this unconformity is not everywhere visible, the Shinarump conglomerate was found abutting against a cliff of Permian beds on the east side of the Kaibab fold near Paria, Utah. To the west the shales above the conglomerate overlap the latter and come in apparent conformable relations with the Permian strata.

The sections of Mesozoic formations made by Walcott in Kanab valley have never been published, but through his courtesy I am permitted to give a typical one of the Jurassic and Triassic beds.

Section of Jurassic and Triassic formations in the Kanab valley, Utah

Made by C. D. Walcott in 1879

Top		Feet
	Cretaceous strata occur above this section.	
1.	White friable sandstone, stained yellow locally	75
2.	Cream-colored arenaceous, friable rock, somewhat gypsiferous	275
3.	Red arenaceous shales	150
4.	Conglomerate of quartz pebbles and fragments of sandstone and limestone with calcareous cement	50
5.	White massive beds of gypsum with irregular partings of white marl	30
6.	Red marl and conglomerate, the latter very variable in thickness	115
7.	Red arenaceous and gypsiferous shale and marl	50
8.	Cream-colored magnesian limestone, with many small cavities in upper portion and fossil-bearing at 6 feet below top Fossils: *Myalina* sp.? *Camptonectes bellastriatus*, *C. extenuatus*, ? *C. stigius*, *Pecten* n. sp., *Myophoria ambilineata*, *Astarte?* sp.? *Trigonia?* sp.? *Ostrea strigilicula*, *Solarium?* sp.?	25
9.	Sandy shale with few indurated layers; contains many fossils	75
10.	Limestone	10
11.	Sandy shales	65
12.	Buff and cream colored, fine-grained magnesian limestone in layers from ¼ inch to 2 feet thick	40
13.	White Cliff sandstone, massive, cross-bedded, light-gray, broken into five principal belts by horizontal lines of bedding	585
14.	Vermilion sandstone; cross-bedded, friable, readily disintegrating, forming the foothills and slope to the more compact sandstones at the northern end of Vermilion Cliff canyon	650
15.	Gray and reddish-brown, cross-bedded sandstone. Horizontal beds of varying thickness divide the mass into bands of from 25 to 100 feet in thickness	300

Section of Jurassic and Triassic formations in the Kanab valley, Utah—Continued

Top		Feet
16. Evenly bedded red sandstones. Upper portion an indurated, dark reddish brown stratum. Indurated layers alternate with more friable layers and shales beneath		120
17. Massive gray sandstone, cross-bedded. Upper portion is a light-gray massive friable bed. The entire mass is subdivided into six principal beds by subhorizontal lines of bedding of a dark, more indurated sandstone. The beds are from 20 to 80 feet in thickness, and may be seen on many steep escarpments along the canyon		310
18. Solid, partially cross-bedded sandstone, changing from gray to various shades of red		20
19. Evenly bedded, light-red sandstone with a thin layer of intercalated gray sandstone		20
20. Dark-red sandstone; massive layers alternating with shale, which disintegrates and forms a sloping talus to the gray sandstone beneath		180
21. Light-gray sandstone		5
22. Bedded sandstone of various shades of red and gray. The layers of sandstone and their shaly partings are irregular in thickness. Scolithus borings occur in great numbers in a friable yellow sandstone. Fragments of vegetable matter and carbonized wood also were seen		230
23. Thin layers of sandstone, alternating with bands of fine argillaceous shale holding fish teeth and shells		25
24. Massive, light-brown sandstone, broken up into thick layers		50
25. Alternating layers of sandstone and fine argillaceous shales with fish teeth, etc.		25
A detailed section of 25 is as follows:		
a. Light sandy layers with shaly partings	7	
b. Fine, smooth, arenaceous and argillaceous shales, drab-brown to red with fillets of green. A few fish scales were found	6	
c. Fine-grained, light-colored sandstone, 2 to 4 feet in thickness	4	
d. Same as (*b*), only more fossiliferous. The entire band varies from 20 to 25 feet in thickness. Great interest is attached to this bed, as up to the present time it has afforded more fossils than have been obtained from the rocks between the Shinarump conglomerate and the Jurassic limestone. They include ichthyic remains, Entromostracans and Conchifers	8	
26. Reddish-brown friable sandstone, broken into layers 1 to 6 feet thick, with shaly partings		120
27. Alternating bands of marls and shales, with layers of friable light and reddish-brown sandstone		70
28. Reddish-brown sandstone broken up into layers 2 to 7 feet in thickness with a stratum of gray sandstone at the base		20
29. Arenaceous and earthy gypsiferous shales; marlites, purple, brown, bluish-green, and green, forming low, rounded foothills and slopes from the Vermilion cliffs to the Shinarump conglomerate		650
30. Gray conglomerate and sandstone. Conglomerate formed of small, agatized pebbles and holding silicified wood		50
Total		3,430

The basal conglomerate of this section is called the Shinarump conglomerate by Walcott (39) and is said to rest unconformably on the Permian beds.

Comment on Walcott's Kanab section.—In this Kanab section it is evident that numbers 1 to 12, inclusive, aggregating 960 feet in thickness, represent the upper Jurassic group called the Flaming Gorge by Powell. Number 13 is the White Cliff sandstone, considered as the lower Jurassic in this discussion, but placed by Powell in the Trias. Mr Walcott comments in his notes upon the absence of a sharp line between this sandstone and that below it. Reasons why an apparent transition at this horizon is natural have been presented. This thickness of the vermilion-colored sandstone, 14 of the section, was found to vary from 600 to 700 feet on opposite sides of the valley where the section was made, a variation which may possibly be due to erosion.

It is noteworthy that the White Cliff sandstone is thinner in Kanab valley than it is to the east, where Dutton and Powell refer to it as a thousand feet thick. Beneath the White Cliff sandstone occur 2,845 feet of beds, which are referable to the Trias. It is not certain just what represents the Vermilion Cliff sandstone of Dutton, said by him to be 2,000 feet thick near the Virgen river and 1,400 or 1,500 feet thick in the zone crossed by the Kanab (9, page 40). It would appear, however, that beds 14 to 20, inclusive, in all 1,600 feet of sandstones, represent the Vermilion Cliff of Dutton, although the distinctive color is not present throughout. Assigning the beds specified to the Vermilion Cliff, the remainder of the section, embracing 1,245 feet of beds, must be referred to the Shinarump group of Powell.

The Shinarump of Kanab valley, thus delimited, carries fossil wood in the basal conglomerate and at various horizons in the upper portion. Far more interesting than the silicified wood, which has not been studied by paleobotanists, are the fish and other animal remains obtained by Walcott in beds 23 and 25 of the section—that is, in the upper third of the Shinarump.

These fossils were sent to the National Museum, and in the confusion of inadequate storage facilities were lost sight of until a few months ago. On being found they were sent to Dr C. R. Eastman for identification and description. Doctor Eastman's complete identifications are not yet available, but he has published a brief preliminary reference to the ichthyic fauna, from which the following is abstracted:

> "These remains . . . are extremely fragmentary and do not permit of accurate specific determination. Of the few genera, which are tolerably well indicated, such as *Pholidophorus* and several *Lepidotus*-like forms, it can not be said that they evince anything in common with the Triassic fauna of the eastern states. Some resemblance is to be noted between the Kanab fish fauna and that of Perledo near

Lake Como, but the general aspect of the material collected by Doctor Walcott is suggestive of Jurassic, rather than of Triassic relations. This might very well happen, notwithstanding the horizon be definitely proved by stratigraphic and other evidence to be of Triassic age, as other instances of pioneer faunas and overlapping contingents are not uncommon" (10*a*).

Associated with the fish remains there were found several representatives of other classes of animal life, concerning which Doctor Eastman has given me the following comments, pending more careful investigation: "There is one ammonite in the collection, or rather a portion of the outer volution of one, which is very suggestive of the Liassic *Arietidæ*, and in the opinion of Doctor Jackson and Mr Shimer, who have examined it, does not seem to belong to the class of forms known from the Pacific Coast Trias." There are numerous *Estheria* in the collection and fragmentary saurian teeth, but whether of crocodilian or ichthyosaurian forms Doctor Eastman is unable to determine.

From the statements of Eastman it appears that the Kanab fauna obtained by Walcott is unique and raises several interesting problems for solution. The fossil-bearing strata were traced by Walcott from the Kanab eastward to the Colorado river, and thus are known to occur not far from the area in which the Saurian fauna of the Little Colorado was obtained by Ward and Brown, both faunas belonging apparently to the Shinarump group. The relations of the two fossiliferous horizons are as yet quite unknown. From the stratigraphic standpoint it is difficult to see how the Kanab fossils can possibly be of Jurassic age, unless there are complications, hitherto wholly unsuspected, in the great section of the Plateau country.

NORTHEASTERN UTAH AND NORTHWESTERN COLORADO

The Triassic and Jurassic formations of the eastern Uinta mountains, as exposed near Green river and in the Yampa plateau, have been described by Powell, King, Emmons, and White. Powell (36) applied the divisions of the Plateau country to this northern field. King (24) and Emmons (16) described the formations in terms very similar to those of Powell. They mention a greenish limestone occurring below the red sandstone (Vermilion Cliff) in which a single shell, *Natica lelia*, was found (24, pages 259, 263, 264). All these geologists referred the White Cliff sandstone to the Triassic, recognizing as Jurassic only the Flaming Gorge group of Powell, with its marine fauna in the basal limestone.

The Hayden Survey geologist working in this area, Dr C. A. White, considered the section between the Carboniferous and Cretaceous as belonging to one system, of continuous sedimentation, and as probably Jurassic for the most part, and applied the term Jura-Trias to the whole (43, page 27). This opinion seems based mainly on the discovery by Howell, in 1874, of a supposed marine Jurassic fauna in the lower part of the Shinarump group, in southern Utah (36, pages 80, 81). In fact, the fossils obtained by Howell belong, as I am informed by T. W. Stanton, to the Permian fauna reported by Walcott (39) from Kanab valley, and which was also found by the Fortieth Parallel geologists in the Wasatch mountains and by them called Permo-Carboniferous (24). This mistake in regard to Howell's collection seems to have been largely responsible for the idea long prevalent with many geologists, that the Jura and Trias of the western United States belonged to one system.

CORRELATIONS WITHIN THE ROCKY MOUNTAIN PROVINCE

Difficulties of the correlation.—The Red Bed section of the mountainous portion of Colorado and Wyoming is clearly not divisible into the units traceable throughout the Plateau province. The evident general reason for this is that the intervals of orogenic disturbance and erosion preceding and following the Triassic sedimentation were here much more productive of stratigraphic breaks than in the Plateau area. There is much evidence of these effects cited by the Hayden Survey geologists, and even more is indicated on the Hayden geological maps of Colorado. Furthermore, the changes in lithologic character in the mountain province are much more notable and render correlations less certain. So great is the variance between the sections exposed in different parts of the mountains that an attempt to review the literature in detail would go far beyond the limits which must be assigned to this discussion. Until many districts have been reexamined with care, it will be premature to attempt direct correlation of the Dolores and Cutler formations as such with the elements of sections in central and northern Colorado; but there are various facts bearing on the distribution of Triassic and Carboniferous Red beds which may be briefly presented.

Fossiliferous Trias on Red Dirt creek.—The presence of fossils in the Red beds on Grand river, some 130 miles north of Ouray, was announced by R. C. Hills (20) in 1880, in the note calling attention to the fossiliferous Trias of the San Miguel river, the Dolores formation. Red Dirt creek, where Hills found a " bone bed " resembling that of the San Juan region, is some 12 miles above the mouth of Eagle river and heads on the eastern side of the White River plateau.

About 20 miles farther north the Hayden map (19) represents the Trias as overlapping the edges of Paleozoic beds and coming in contact with the Archean rocks of the Park range. Whether this relation is due to the pre-Dolores disturbance and erosion remains to be proven, but it seems entirely reasonable to suppose that it may be of that origin.

The impression that the fossil-horizon of Red Dirt creek is the same as that of the Dolores formation remains to be demonstrated by a collection and study of the fauna, but the discovery of Triassic vertebrates near Lander, in central Wyoming, lends strong support to the correlation suggested by Hills.

Triassic beds of central Wyoming.—The Triassic fauna from Wyoming just referred to has been partially described by Williston in a paper published since the major part of this discussion was written (44). While the few forms described are new to science both generically and specifically, their Triassic affinities are maintained by Williston. Among them are representatives of the Anomodontia allied to *Placerias* Lucas, from the Le Roux beds of Arizona, and a phytosaur related to Belodon and evidently similar to *Heterodontosuchus ganei* Lucas, the common fossil of the Dolores beds.

The occurrence of the beds containing these and other fossils has not been announced further than that the locality is near Lander, on the Popo Agi river, which name is applied to the formation by Williston, with the statement that it will be described by N. H. Brown, the discoverer, and himself.

Other localities of Triassic vertebrate remains are known in southern Wyoming, although not yet described, and it appears to the writer not improbable that by systematic work the continuity of a Triassic fossil-bearing formation may be established from Wyoming southward to the outcrops noted by Hills adjacent to Grand river. It is possible, of course, that the post-Triassic erosion may have removed the Triassic beds over considerable areas, as seems to be indicated by the Hayden map.

Permian Red beds of the Laramie basin.—Turning now to the lower part of the Red beds, evidence has recently been presented by the late W. C. Knight (24*a*) showing that in the Laramie basin of southern Wyoming the Triassic strata of Hayden and King should be referred in part at least to the Carboniferous system and probably to the Permian series. Knight gives a section of 1,578 feet of Red beds which rest on granite. A little below the middle of this section a fossiliferous sandstone was found, the fauna resembling "to a marked degree the fossils of the Kansas and Nebraska Permian." Only one thin limestone was noted in the section, but Knight made the significant observation "that the strata of the lower portion of the Red beds are identical with the strata of limestones to the northward, the difference in the lithological characteristics being due to the varied physical conditions during sedimentation."

These limestones also contain in their upper portion a fauna resembling that of the Kansas "Permian," but Knight remarks that Coal Measure fossils have not as yet been collected from the lower beds.

Since Knight could find no stratigraphic or fossil evidence for subdividing the Red bed section of the Laramie plains, he refers it as a whole to the Permian and compares it particularly with the Permian of Kansas and Oklahoma. While that correlation may be correct, it is manifestly going too far to conclude, with Knight, that, "if adopted, it will deprive the eastern Rocky Mountain region of the term 'Triassic' and make the basal member of the Mesozoic the Jurassic."

Accepting the views expressed by Knight concerning the fauna of the Laramie Plains Red beds, it is clear that the section above his lowest fossil-bearing horizon is younger than the Rico formation, but may correspond as a whole or in part to the Cutler formation. Nothing indicated by Knight suggests correlation of the upper unfossiliferous portion of his section with the Dolores beds. It is to be noted, however, that this upper portion contrasts with the lower, in that it does not grade into limestones northward, but overlies the Permian limestones. The unfossiliferous portion whose reference to the Permian is still open to possible doubt is 850 feet in thickness, and it does not appear that the section was complete, up to the Jurassic beds. There is, therefore, ample room for a Triassic formation in the Red beds of the Laramie plains. Even if no Triassic beds are now present in the Laramie region, they may have once existed and have been removed by the pre-Jurassic erosion.

The relation of the Triassic horizon containing vertebrates studied by Brown and Williston to this "Permian" section has not been described.

"*Permian" beds of the Grand and Eagle rivers, Colorado.*—In the vicinity of the Triassic horizon observed by Hills, noted above, the upper Paleozoic section is of very different character from that near Laramie, but its upper portion was assigned to the Permian by Peale (34) on the basis of a few plants considered by Lesquereux as of that age. The strata so referred are gypsiferous shales of various colors, yellow, pink and creamy, with some limestone, and are not to be correlated either with the Laramie Permian or the Cutler beds on present evidence. These gypsiferous beds are overlain by the Red beds of Peale, assigned to the Triassic, and seemingly this division must include the bone bed of Hills, since the succeeding formation is apparently the normal fresh water Jura.

Foothill section of the Front range.—The well known Red bed section of the Front Range foothills in Colorado was assigned to the Trias upon no definite evidence, by the geologists of the Hayden Survey, excepting two small areas at Manitou and in Perry (Pleasant) park. A special map of the Manitou region, contained in the annual report for 1874 (18), distinguishes "a peculiar group of strata not observed elsewhere on the eastern slope" as Carboniferous. No good reason for referring these particular strata to the Carboniferous was given by Hayden, and the unique character of these beds thus asserted is not evident to recent observers.

In the Pikes Peak folio, issued in 1894, the writer established the Fountain formation to include about 1,000 feet of coarse, reddish arkose sandstones, grits, and conglomerates, occurring in the small interior basin of Manitou park and the corresponding beds, with which they were once connected, in the foothill belt at Manitou and the Garden of the Gods. The latter apparently embrace the strata called Carboniferous by Hayden. I also assigned to the Fountain formation the Red beds of the Canyon City embayment, and Gilbert (Pueblo folio) did the same in 1897 for a small isolated area to the south, occurring in the Pueblo quadrangle. Gilbert, however, provisionally assigned the Fountain beds to the "Jura-Trias."

My reference of the Fountain formation to the Upper Carboniferous (Pennsylvanian) was in the belief I still hold that its most plausible correlation is with the strata of similar character, except for thin limestones exposed in the folded section crossing the Arkansas river below Salida. In the limestones of this section Eldridge once obtained a few Pennsylvanian fossils, afterward lost and hence not considered in Girty's review of the Colorado Carboniferous faunas (15). These strata form some part of the indefinite aggregate called the "Arkansas sandstones" by Endlich, and they extend south into the Sangre de Cristo range, where fossils were found sparingly by Endlich and other early explorers. Curiously enough, Endlich did not discuss any possible connection of the Arkansas sandstones with the rocks near Manitou called Carboniferous by Hayden.

A remnant of Carboniferous beds occurs at the south end of the Greenhorn range, and this has been called the Badito formation by Hills (22).

The base of the Fountain Red beds in the Pikes Peak quadrangle is a plane of more or less pronounced unconformity with lower formations. The whole of the formation is not preserved in that quadrangle, owing to either Mesozoic or Recent erosion, but in the section on and near Fountain creek, below Manitou, it is plain that the natural lithologic limit of the Fountain is a light colored, fine grained, quartzose sandstone well shown in the Garden of the Gods. This sandstone is apparently equivalent to the "Creamy sandstone" of the Denver region, as Darton has pointed out (7).

In the Denver monograph Emmons and Eldridge (11) named the entire Red bed section of that district the Wyoming formation, distinguishing within it the lower and upper divisions, on purely lithologic grounds. The Lower Wyoming embraces beds like the Fountain in lithologic character and, in addition, the quartzose Creamy sandstone. Both Emmons (11) and Darton (7) have recognized the resemblance of the red arkose strata of the Lower Wyoming to the Fountain beds; but the suggestion of the latter (7) that the Fountain and Lower Wyoming are quite equivalent is to my mind less natural than to consider the Lower Wyoming a group embracing the Fountain beds and the lithologically distinct "Creamy sandstone," which Darton thinks is equivalent with the Tensleep sandstone of the Big Horn mountains, Wyoming (7), and which in any case deserves a special name.

The Upper Wyoming of the Denver region embraces the remainder of the Red bed section, and it is referred to the Trias by Emmons and Eldridge. Darton, however, in his valuable discussion as to the correlation of formations of the Black hills, Big Horn mountains, and the Front range (7) presents reasons for supposing that the Upper Wyoming, as developed near Denver, may be wholly referable to the Permian series. This is based on stratigraphic relations and the belief that a limestone occurring shortly above the "Creamy sandstone" is the equivalent of the Minnekahta limestone of the Black hills, where it contains *Bakewellia* and *Edmundia*, forms apparently identical with those characteristic of the so-called Permian of the Mississippi valley.

Poorly preserved shells of similar appearance were found in a limestone at Morrison. Darton believes that the Opeche and Minnekahta (Permian) and the Spearfish (Triassic?) formations, distinguished by him in the Black hills, extend southward through Wyoming into northern Colorado, but as their exposures are not continuous, and as lithologic details vary in the different areas of outcrop, he proposed Chugwater as a group term, which is thus practically equivalent to Upper Wyoming. Darton states that the upper or Triassic (?) portion of the Chugwater group thins out and disappears before the Denver area of Red beds is reached, leaving only the supposed Permian as present in the Morrison and Golden sections especially described by Eldridge (11).

From the brief review just given it appears that the Red bed section of the Front Range foothills contains no member to be correlated with the fossiliferous Triassic (Dolores) of the western portion of Colorado. The views of Darton and the writer harmonize in referring the entire Red bed sections of the Denver region and southward, at least to the Canyon City embayment, to the Paleozoic. The Fountain beds seem to me to be synchronous in origin with the Pennsylvanian formations of the San Juan region. An unconformity separates each from the Mississippian Carboniferous (Millsap or Ouray) and above each in apparent conformable relation is a non-fossiliferous complex of Red beds. On the west slope these are embraced in the Cutler formation, while at the base of the Front range is the more variable section of the Wyoming group, succeeding the Fountain. That the beds of the Wyoming group (excluding a possible Triassic portion) are coextensive with the group consisting of the Molas, Hermosa, Rico, and Cutler formations of the San Juan is of course not to be assumed.

Searching for probable equivalents of the Dolores Triassic to the east of the mountains, we are at once confronted with the condition, long known, that the Morrison formation—whether Jurassic or Lower Cretaceous matters not to this discussion—rests unconformably on the older formations, the transgression being very gradual.

It is plain that the Morrison beds rest on the Fountain grits in the Pikes Peak quadrangle, the "Creamy sandstone" and the entire Upper Wyoming section of the Denver area being missing. The thickening of the Chugwater group northward, recorded by Darton, is probably due, in part at least, to this same transgression.

The Spearfish formation of the Black hills, embracing some 700 feet of gypsiferous sandy Red beds, is referred by Darton (7) to the Trias, without fossil evidence, from its stratigraphic position between the supposed Permian and the marine Jura (Sundance). The Spearfish is conformable with the beds below, but the Sundance is unconformably on it. In view of the apparent absence of the widely distributed Triassic vertebrate fauna and the conformity with the Permian (?) below, the Triassic age of the Spearfish seems to me open to much doubt. I think it may more plausibly be viewed as embracing a part of the uppermost Palezoic section not now preserved at any point to the south, as far as known. Whether the Spearfish beds of the more southern area were removed by pre-Triassic erosion, or, together with Triassic sediments, by the pre-Morrison erosion, is an interesting question upon which there is little evidence.

Of important bearing on the problem of Triassic sediments to the east of the mountains is the discovery recorded by Darton (7) of a Triassic vertebrate, determined by Lucas as belonging to a belodon, in Red beds of the canyon of the Purgatoire, a southern branch of the Arkansas river, in Colorado, some 70 miles below Pueblo. Since this locality is on the plains, many miles from any well-known section of the foothills, and without exposure of underlying formations, the correlation of the fossiliferous horizon with any part of the Front Range Red bed section is hazardous, as Darton points out (p. 441). But since the belodonts are the most common forms in the Triassic beds of a great area, as brought out by this discussion, the general correlation of the Purgatoire horizon with that elsewhere known to contain the belodont fauna is directly suggested.

According to Darton (7) the fossiliferous Red beds of the Purgatoire have been traced by Lee into northern New Mexico, and this at once raises the interesting question as to the relation of the Purgatoire horizon with that of the Gallinas mountains, some 200 miles farther west in New Mexico, where the first Triassic fossils of the West were discovered by Newberry in 1859; but before further discussion of this connection, it is necessary to refer to the possibility that Triassic beds occur in the Canyon City region.

Among the many remarkable fossils described by Marsh (31) from the vicinity of Canyon City is a small Dinosaur, *Hallopus*. With his habitual disregard of stratigraphic relations, Marsh gave neither precise locality nor horizon for this fossil, treating it as belonging with the Atlantosaurus fauna, but it has recently been announced by Williston (45) that *Hallopus* is, in his opinion, of Triassic affinities, while the Atlantosaurus fauna is considered Lower Cretaceous. It is certain that no considerable thickness of Triassic beds can exist between the Morrison and Fountain formations in the Canyon City-Garden Park district, but a thin Triassic remnant may well be present, locally at least. The relation of the *Hallopus* horizon to the Belodon bed of the Purgatoire canyon is of course wholly unknown.

Triassic beds of northern New Mexico.—While Marcou and other early explorers of New Mexico announced the presence there of Triassic formations, the first fossils indicating the correctness of this assertion were obtained by Newberry in 1859. The fossils described by Newberry himself were fossil plants obtained from the old copper mines near Abiquiu, a locality on Chama river some 20 miles or less above its junction with the Rio Grande (33, pages 67–69). The plants are mainly cycads and conifers, and as they have not been identified at many other localities they are of less importance to the present discussion than the vertebrate remains described by Cope, to which reference will soon be made.

The formation from which the Abiquiu plants were obtained is described by Newberry as consisting mainly of red sandstones, with conglomerates and many variegated beds of soft shales, with abundant saline efflorescences, which led him to characterize the Red beds of New Mexico and Arizona in general as the "Saliferous series." Fossil wood, often in tree trunks, is mentioned.

Although I can not find that Newberry mentions vertebrate fossils in the Triassic beds of Chama valley, it appears that he found some, for Cope, who followed him in the exploration of the region, states that the first invertebrates from the Trias of the Rocky mountains were collected by Newberry with the Macomb expedition. Cope visited Chama valley and the Gallinas mountains, lying to the west of it, in 1864, while on the Wheeler Survey, and obtained various vertebrate fossils from the Triassic beds (1).

The fragmentary remains described by Cope embrace teeth and bones of 3 dinosaurs, 2 of which were generically determined as *Laelaps* and *Palæoctonus*. Similar portions of a belodont crocodile were called *Typothorax coccinarium*. Associated with these were found 5 species of *Unio*·

This assemblage of forms suggests the fauna of the Dolores "saurian conglomerate." The locality is less than 100 miles southeast from the easternmost known exposures of the Dolores formation, the intervening country being occupied by Cretaceous formations. It is therefore very natural to suppose that the vertebrate and plant-bearing Trias of Chama valley may be the direct equivalent of the lower Dolores formation. Apparently the fossiliferous strata of New Mexico are not overlain by a massive red sandstone equivalent to the Wingate sandstone of Dutton. The "Variegated Marls" of Newberry, which seem clearly to belong to the McElmo or Morrison beds, intervene between the "Saliferous series" and the Cretaceous.

The Gallinas mountains, where Cope obtained his Triassic vertebrates, are probably considerably less than 200 miles west of the district into which Lee is said to have traced the Red beds of the Purgatoire (see page 493), and while the lithologic characters of the belodont-bearing strata of the two districts are possibly quite different, it is a natural suggestion from both stratigraphic and paleontologic grounds that they may represent practically one horizon.

SUMMARY.

Some of the more important conclusions drawn from the facts and isdcussion presented in the foregoing pages may be summarized as follows:

1. A marked angular unconformity is exhibited near Ouray, Colorado, between a well defined fossiliferous horizon of the Dolores Triassic formation and an extensive section of Paleozoic beds, including the Cutler Permian and the Hermosa Pennsylvanian formations.

2. The Ouray unconformity is evidence of a stratigraphic break, of as yet unknown importance, in the midst of the Red beds of western Colorado. There are reasons to suppose that this hitherto unrecognized break is widespread and explains many discordant features of various Red bed sections, not only in Colorado, but in the adjacent Plateau province.

3. The fossiliferous horizon of the Dolores formation, occurring above the unconformity noted, has been traced down the Dolores and San Juan valleys into the Plateau province. The sections of the mountain and plateau districts are comparable in many ways.

4. A vertebrate fauna, similar to or identical with that of the Dolores formation, has been found at widely separated points in New Mexico, Arizona, Utah, Wyoming, and Colorado, and paleontologists regard it as clearly of upper Triassic characteristics.

5. Through the stratigraphic correspondence of the Red beds and associated formations in the Rocky Mountain and Plateau provinces and

the evidence of the Triassic vertebrate fauna at numerous points, certain correlations are more or less clearly indicated.

a. The Hermosa formation appears to occupy the same stratigraphic position as the Aubrey of Utah and Arizona. Further investigations are necessary, however, to explain certain faunal differences or dissimilarities noted by paleontologists between the formations.

b. The Cutler formation, being older than the Ouray unconformity, is probably of Paleozoic age and corresponds more or less closely to the Permian portions of the stratigraphic sections of the Plateau and Mississippi Valley provinces.

c. The Dolores formation includes diminished equivalents of the Shinarump and Vermilion Cliff formations of the Plateau. The Shinarump may include important divisions not represented in the Dolores.

d. The La Plata formation is seemingly equivalent to the White Cliff sandstone. Its local assumption of red color has led to confusion with the Vermilion Cliff in certain districts and a reference to the Trias. Since the White Cliff sandstone underlies marine Jurassic beds, and the La Plata transgresses the Dolores and all older beds in marked unconformity, the Jurassic age of the lower division of the Gunnison group seems established.

e. The McElmo formation appears to correspond closely to the Morrison and Como beds and the Flaming Gorge group of Powell. It is probable that the marine Jurassic horizon belongs between the La Plata and McElmo formations.

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TERTIARY LIGNITE OF BRANDON, VERMONT, AND ITS FOSSILS

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(*Presented before the Society December 30, 1904*)

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HISTORICAL SKETCH

In 1846, while sinking a shaft to reach a bed of limonite near Brandon, Vermont, the workmen came upon a deposit of brown coal or lignite, which at the time attracted only local attention. Five years later, in 1851, some of the lignite and fossils found in it were sent to President Edward Hitchcock at Amherst. As a result of this, President Hitchcock soon visited the locality and wrote a description of it, which was published in the American Journal of Science and Arts,* 23 figures of the fossils being given, but none of them were described or named. Not long after the above publication, Doctor Hitchcock sent some of the fossils to Mr Lesquereux, who published descriptions and names of the specimens in the Journal.* Both of these papers are reprinted in the Vermont Geological Report of 1861.

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* Vol. xv, 1853, pp. 95–104.

Nothing further concerning the lignite appeared until in 1902 Doctor F. H. Knowlton published in Torrey Bulletin † an account of the lignite and of some of the fossils, 4 species of which are figured on plate xxv of this article, and also several microscopic sections of lignite and fossils.

A much larger amount of material than had been obtained before having come into the possession of the writer, he was able to publish in his Fourth Report as Vermont State Geologist, in 1904, a more extended account of the deposit and its fossils than had previously been possible. As the edition of this report was not large, and hence copies could not be as widely distributed as might have been desirable, it is hoped that a summary of the results obtained from a careful study of a large quantity of the lignite will not be without value. Since the report was published considerable new material has been studied and the following pages should be regarded as a revision rather than a reprint of the account given in the report.

LOCATION AND EXTENT OF THE LIGNITE DEPOSIT

The accompanying sketch map, made by Professor T. N. Dale, after an examination of the locality, shows the position of the lignite and associated deposits so far as known.

It is to be noted that the lignite does not occupy nearly all of the small shaded area, but only a small part of it, as most of the space indicated is occupied by clays, limonite, kaolin, etcetera. Doctor Hitchcock's account indicates that in his time there was some outcropping of lignite at the surface, but for many years this has not been true, and now the bed is covered by from 10 to 60 feet of drift. For this reason the lignite is never seen except as it is brought to the surface through a shaft. At present the only shafts from which it has been obtained are one near the upper end of Professor Dale's shaded area and another about 600 feet south of it. These two shafts have afforded quite unlike material and do not appear to enter the same deposit. All of the fossils found have come from the shaft near the upper end of the shaded area seen in figure 1, a few rods above the crossing of the roads, while the shaft on the southern part of this area has produced a more compact and harder lignite, apparently more completely carbonized, and yielding not a single fossil.

It will be seen readily that the real extent of the lignite deposit is not known, but it seems certain that it can not be very great. The thickness appears to be about 20 feet, but in places it may be more, as in one of the shafts sunk some years ago 50 feet were found and the shaft was not sunk through it. This greater thickness is, however, in part due to the dip of the bed, for it inclines strongly toward the west, as various shafts show. It is, of course, possible that future investigations will show that the deposit is much more extensive than it now appears, as Doctor Hitchcock evidently supposed, but so far as we now know, it is of very small area.

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* Vol. xxxii, 1861, pp. 355-363.

† November, 1902, pp. 636-641.

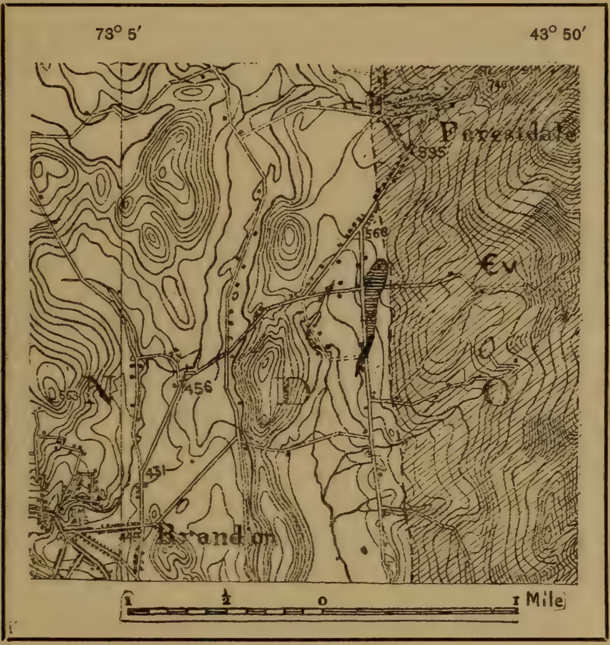

Figure 1.—*Map of the Brandon Lignite Area.*

Contour interval 20 feet. Topography by U. S. Geological Survey. *Cv* = Cambrian quartzite and schist. Dark area = lignite, kaolin, and limonite.

Associated Deposits

The lignite appears to be always surrounded by some sort of clay, and at present the only work done in the locality is for the purpose of obtaining a pure white clay, kaolin, in which when dug there is a considerable mixture of white sand from the decomposition of associated quartz rock. There appears to be a large bed of the white kaolin, but clay of various shades of red and yellow also occurs. The workmen in the shafts declare that white clay is always found in contact with the lignite. Bits of white quartz, usually quite small, are often abundantly intermingled with the lignite.

AGE OF THE LIGNITE

None of the shafts have reached the underlying rock, so that it is not known what is directly below the deposit. The age of the lignite is, at least approximately, fixed as Tertiary by the fossils. Doctor Hitchcock considered it as "Pliocene or newer Tertiary." In 1863 Mr Lesquereux wrote:

> "Most of the fruits published, or rather figured, can be referred to the species of the Upper Tertiary. They agree especially with the flora of Oeningen, and I have no doubt that the Brandon lignites belong to the same epoch as the upper bed of lignite of the Tertiary."

By this must be meant the Miocene.

In the last edition of Dana's Manual we find the statement that "the Brandon lignite is probably of Eocene origin." Professor Knowlton, however, thinks that this is "a conclusion which later investigation will not sustain." And yet he says of the structure of some specimens of the lignite, "Indeed after careful study I am scarcely able to distinguish the Brandon lignite from a species of Pityoxylon described by Schmalhausen from the Eocene and Braunkohle of southwestern Russia," and decides that the Brandon specimens are only a variety of the Russian form.

Stratigraphically we have no help, for so far as position is concerned the lignite may be placed anywhere between the Cambrian and the Quaternary. While the deposit may be either Eocene or Miocene, the fossils, in the judgment of the writer, are more closely allied to modern than to ancient forms—that is, they are more Miocene than earlier.

APPEARANCE AND CHARACTER OF THE LIGNITE

The lignite is always dark brown in color, though the shade varies from that which is much like that of ordinary decayed wood, which some specimens closely resemble, to that which is black like jet. In much of it the grain of the wood is distinctly visible, but there is also not a little in which no fiber can be found, nor any trace of the original structure, except by careful examination under the microscope, but not always then. The density and hardness also vary greatly. Some of it can be easily cut; a few specimens are as hard as soft coal. Usually it breaks easily, a light blow of a hammer sufficing to shatter a good-sized piece, but in some cases it can not be easily broken. When protected, as in a museum, it often remains indefinitely unchanged. I have seen in several museums pieces that had been in the cases 40 or 50 years, being among the first found, and these do not appear to have changed in any respect.

In some specimens pyrite is present, and of course these are likely to crumble.

When thrown out of doors, however, most of the lignite soon breaks up into angular fragments and finally becomes a soft, muddy mass.

The fossils are less liable to decomposition and are often well preserved long after the surrounding material has been reduced to a shapeless mass.

When first taken out, the lignite is usually in small pieces, from those as large as one's two fists down to mere bits. The largest piece of which I have knowledge is one sent many years ago to Doctor Hitchcock, who placed it in the Amherst museum, where it still may be seen. This piece, to which Doctor Hitchcock has referred in his account of the locality, is 19 inches long, 16 inches wide, and 6 inches thick. In the museums at Burlington and Montpelier there are 2 or 3 pieces which are smaller than the above, but still large.

Use and Value as Fuel

Soon after its discovery the lignite was used as fuel, though only at long separated intervals and in small quantities. The attempts to substitute it for coal or wood were never successful, and after a brief trial it was abandoned as impracticable. During the coal famine which occurred in the fall of 1902, the lignite was brought into use much more extensively than before. At this time over a hundred and fifty tons were dug and sold in and about Brandon. Some of the housekeepers who used it in cook-stoves spoke highly of it, while others found it very troublesome and not at all satisfactory. The fact that all who had been using the lignite were very glad to return to coal, although it was then sold at a high price, is sufficient proof of the inferiority of the lignite. Still it has been abundantly proved that it will burn, and that in case of need it can be substituted for wood or coal. It burns readily with a yellow flame and gives off a peculiar though not unpleasant odor. It leaves a large amount of ash, is soon exhausted, and even at its best does not produce as much heat as coal.

Botanical Character

Investigation shows that some of the lignite was formed from dicotyledonous and some from coniferous wood. It is also very probable that some of it is from endogenous wood, but this has not yet been determined.

In 1853 Doctor Hitchcock wrote:

> "With perhaps one or two exceptions, all the lignite of this deposit belongs to the exogenous class of plants. The bark is often quite distinct. I have been inclined to refer some of the wood to the maple, yet probably a good deal of it is coniferous."

In a letter dated December 10, 1852, Professor J. W. Bailey stated that "the woods are not coniferous and do not present characters by which I can distinguish them from any ductiferous woods."

In 1861 Mr Lesquereux wrote as follows concerning a piece of the lignite which had been sent to him:

> "The wood, though somewhat hardened and blackened, is still in a good state of preservation. It is soft enough to be cut with a knife, or at least easily broken, and by a section shows on both sides the characters of dicotyledonous wood."

In the article by Professor Knowlton referred to on page 500, we find him saying of the pieces which he examined that "a large portion of the lignite is undoubtedly coniferous in character." Still this author describes and figures "one small, but well preserved piece that is dicotyledonous."

A series, including numerous samples taken from as many different pieces of lignite as possible, was sent to Dr E. C. Jeffrey, of the Harvard Botanical Laboratories. While Doctor Jeffrey's examination is not yet completed, he writes of that which he has studied as follows:

> "Most of it is a species of Lauroxylon. There is one small piece of coniferous wood and a good deal of dicotyledonous material in which only the medullary rays show any structure."

The fossil fruits found in and with the lignite are mostly those of exogenous trees; a few may be from coniferous trees and a few from palms or allied species.

The only explanation which suggests itself, in view of the discrepancy in the above quotations, seems to be that lignite from one part of the deposit may be quite different from that taken in another part and at a different time. As has been noted, Doctor Knowlton considered much of the lignite which he examined as a variety of that from southern Russia named by Schmalhausen *Pityoxylon microporosum*, and for the Vermont lignite Doctor Knowlton proposes the name given by Schmalhausen, adding the variety name of *brandonianum*. This name, however, can not apply to more than a comparatively small part of the Brandon material.

Fossils of the Brandon Lignite

DIFFICULTY OF OBTAINING SPECIMENS

As has been stated, the lignite deposit is covered heavily by drift, and consequently it is not ordinarily possible to get at it. Were the material itself of sufficient value to warrant mining, the fossils would probably become very common, but they can only be obtained when digging for kaolin or some other associated deposit. For this reason the fossils which are peculiar to this locality are very rare and will probably always be so.

Prior to 1902 all the existing specimens, so far as diligent search and inquiry have shown, numbered at most only a few hundred. The unusual quantity of lignite removed during the scarcity of coal afforded an opportunity for collecting the fossils which was fully improved. By having collectors on the ground to watch every mass brought to the surface and to take out all the fruits that they could find, I succeeded in getting several thousand more or less perfect specimens. These with the museum specimens at my disposal constitute the material on which this paper and that in the Vermont report of 1904 are based.

LOCATION OF COLLECTIONS

As specimens of these interesting fossils are, so far as I know, found in but few of our museums, it seems desirable to mention where they can be seen.

Aside from the large series in the Vermont state museum at Montpelier, which contains all the types figured in the fourth report, and the almost equally fine collection in the museum of the University of Vermont, there are good collections in the American Museum of Natural History, New York, the Museum of Comparative Zoology at Cambridge, the museum of the Boston Society of Natural History, the United States National Museum, the museums of Amherst, Dartmouth, Yale, Middlebury, and very possibly a few others from which I have not heard. The American museum has the original specimens which Hitchcock figured and Lesquereux described and named, and the Museum of Comparative Zoology has a fine series, including what may well be regarded as cotypes of Lesquereux's species, since they were Lesquereux's own specimens which he received from Doctor Hitchcock.

DIFFICULTY OF IDENTIFICATION FROM PUBLISHED DESCRIPTIONS

Finding himself in possession of the large amount of material which has been mentioned, the writer at first had no other thought than to identify the fossils with published descriptions, but before long it became very evident that this was not possible, nor did comparison with the type specimens in New York facilitate matters very much. Evidently different and often widely separated species were included by Lesquereux under one name, and the whole matter seemed to be in hopeless confusion.

METHOD OF IDENTIFICATION ADOPTED

There appeared to be only two possible courses: Either all that had been published prior to Doctor Knowlton's paper in the Torrey Bulletin must be rejected and a wholly new start made, or as much of the older work as possible might be retained by assuming, more or less arbitrarily, that certain forms represent certain of the described species and regarding as undescribed all that could not properly be so located.

The latter course has been adopted, and it is abundantly justified in the opinion of the author by the conditions existing, as any one who will attempt to use the older descriptions and figures can easily assure himself. For instance, when sections of several specimens plainly included by Lesquereux in the same species were made and examined, it was found that some were one-celled, others two-celled, and still others three-celled. Numerous similar difficulties were encountered. There is no doubt that considerable variation must be allowed in the fruit or seed of many species, but surely there is a limit to this variety.

VEGETABLE REMAINS ONLY FOUND IN THE LIGNITE

It is quite noteworthy that under the conditions existing in the lignite beds there should have thus far been found not a single shell or any other trace of animal life. While hundreds of perfectly preserved fruits have been obtained and a few fragments of leaves, not one trace of animal life has been discovered. The fragments of leaves are few and small and all show netted venation.

COMPARISON OF LIGNITE FRUITS WITH THOSE OF LIVING SPECIES

Much study has been given to the identification of the Brandon fruits with those of modern trees, but thus far without very important results. Indeed it has not been possible to assign most of them to any of the existing genera. As may be seen from the species given on plates 86 and 87, some of the Brandon plants are assignable to modern genera, but none are specifically identical, though some are undoubtedly closely allied to modern forms. Through the kindness of Professor G. L. Goodale, I have had full access to the large collections of seeds and fruits in the Harvard University museum, and Professor B. L. Robinson afforded me the same assistance at the Gray herbarium. I have also had the very efficient help of Mr C. G. Pringle and access at all times to the herbarium of the University of Vermont, which now includes all of Mr Pringle's private collections.

From the above facts it is plain that there has been no lack of recent material for comparison, or of counsel, and yet all that can be affirmed is that the Brandon plants did not produce fruits identical with any living species examined, and that only a small portion of the fossils can be placed in modern genera with any certainty. Professor Goodale called my attention to a collection of fruits in the Harvard University museum from Australia, and a careful examination of these showed a much greater similarity with the Brandon species than I had found anywhere else. So far as it goes, which perhaps is not very far, this would indicate that the Tertiary flora of Vermont resembled that of Australia as it is now more than that of any other part of the world. In appearance these fossils are dark brown, with sometimes smooth, but usually rough—or, at least, somewhat wrinkled—surfaces. A few have polished surfaces, but these are rare. In the Fourth Vermont Report 118 species are described and most of them are figured. Twenty of them are old species. Of both new and old species, two are referred to the genus Pinus, nineteen to Nyssa, one to Juglans, one to Illicium, seven to Hicoria, four to Cinnamomum, and one to Aristolochia. The remainder could not be assigned to any living genera.

None of the fossils so closely resemble modern fruits as do the Nyssas, unless it be the Cinnamomums. The Nyssa shown in figure 10 is larger and otherwise somewhat unlike the living *N. ogeche*, but on the whole the resemblance is very close. The same is true of *N. ascoidea* and the modern *N. aquatica*. Sections in more than one instance showed that fruits very closely alike externally were quite unlike in their internal structure, and it is very probable that a more extended study of the inner structure of these fruits than has thus far been possible will remove some of the doubtful points.

DESCRIPTIONS OF SPECIES

The figures on plates 86 and 87 represent a selection of the more characteristic species. Figure 15 has not been published before, nor have figures 9 and 11, though smaller figures of the same species are given in the Vermont report. To this report those interested in a more extended and fully illustrated account of these fossils are referred.

Brief descriptions of the species figured on the plate are presented below as nearly as possible in the order of arrangement on the plate. The figures are all from photographs taken directly from the specimens, and are natural size unless otherwise stated.

Genus SAPINDOIDES, Perkins, Vermont Geological Report, 1903–1904, page 206.

Sapindoides medius, Perkins.

Plate 86, figure 1.

Fruit small, oval or ovoid, surface wrinkled; length 13 millimeters, width 10 millimeters.

Sapindoides varius, Perkins.

Plate 86, figure 2.

Fruit larger than the preceding, in general ovoid, but often quite irregular in form; surface smooth; length 20 millimeters, width 14 millimeters; surface smooth, but irregularly pitted and grooved.

Sapindoides americanus, Lesq.

Plate 86, figure 3.

Sapindus americanus, Lesquereux, American Journal of Science, volume xxxii, page 357.

Fruit round, oval, more or less depressed at the ends, surface smooth but slightly corrugated; length 20 millimeters, width 14 millimeters. These fruits resemble those of the modern Spaindus, but differ in their internal structure.

Genus Aristolochites, Heer.

Aristolochites majus, Perkins, Vermont Report, 1903–1904, page 206.

Plate 86, figure 4.

Fruit large, oval, costæ little raised, ends rounded, surface somewhat corrugated; length 20 millimeters, width 13 millimeters.

Aristolochites sulcatus, Perkins, Vermont Report, 1903–1904, page 204.

Plate 86, figure 5.

Fruit rather small, oval or subangular, surface bearing six elevated, sharp costæ with wide sulcations between; length 15 millimeters, width 10 millimeters. It is probable that the prominence of the costæ is, at least in part, due to shrinkage as the fruit dried.

Aristolochites elegans, Perkins, Vermont Report, 1903–1904, page 203.

Plate 86, figure 6.

Smaller than most of this genus, ovoid in general form, surface bearing six costæ, which are not prominent; surface smooth; length 12 millimeters, width 8 millimeters.

Genus Apeibopsis, Heer.

Apeibopsis gaudinii, Lesquereux, American Journal of Science, volume xxxii, page 358.

Plate 86, figure 7.

Fruit globular, somewhat flattened at each end when dry, separating into six or seven valves; average diameter 15 millimeters, but the size is quite variable.

Genus Nyssa, Gron.

Nyssa jonesii, Perkins, Vermont Report, 1903–1904, page 197.

Plate 86, figure 8.

Fruit much like that of some modern species. Form elongateoval, unequally ribbed; length 20 millimeters, width 9 millimeters.

Nyssa lescurii, Hitchcock, Portland Society of Natural History, volume i, page 95.

Plate 86, figure 9. (Enlarged twice.)

Fruit elongate-oval, slightly taper-pointed at one end, more obtuse at the other, regularly twelve-ribbed, surface horizontally wrinkled; length 22 millimeters, width 10 millimeters.

Nyssa lamellosa, Perkins, Vermont Report, 1903–1904, page 195.

Plate 86, figure 10.

This is much larger than other species of this genus, and the ribs of other species become thin lamellæ, as is the case in some living species, as *Nyssa ogeche*, which the fossil species much resembles, although it is much larger. This species is long-oval, somewhat flattened, the surface bearing eleven longitudinal lamellæ. These are from five to seven millimeters high and very thin. The ends of the fruit are mucronate. Length 37 millimeters, width 20 millimeters.

Nyssa crassicostata, Perkins, Vermont Report, 1903–1904, page 196.

Plate 86, figure 11. (Enlarged 1½ times.)

It is possible that this and the species figured as 9 should be classed together, but they seem to afford specific differences which are more apparent in the actual specimens than in the figures. This species is shorter, thicker, and less symmetrical than *N. lescurii*, and the costæ are heavier. The ends are blunt pointed. Length 20 millimeters, width 10 millimeters.

Genus Prunoides, Perkins, Vermont Report, 1903–1904, page 209.

Prunoides seelyi, Perkins, Vermont Report, 1903–1904, page 209.

Plate 86, figure 12.

Fruit closely resembling a plum stone, surface smooth almost polished in the center, rough on the edges; length, 15 millimeters; width, 11 millimeters. This is a rare form, only two or three specimens having been found.

Genus Bicarpellites, Perkins, Vermont Report, 1903–1904, page 190.

Bicarpellites knowltoni, Perkins, Vermont Report, 1903–1904, page 191.

Plate 86, figure 13.

This is a fine and well marked species, opening by two valves above, thicker and more rounded below; general form broadly ovate; length 27 millimeters, width 20 millimeters.

Figure 29 shows a cross-section of Bicarpellites.

Bicarpellites rugosus, Perkins, Vermont Report, 1903–1904, page 191.

Plate 86, figure 14.

Form regular elongate-oval, thinner than most of the larger fruits, valve opening only a little more than a fourth of the length, ends rounded. The surface is quite rough and bears irregular longitudinal ridges; length 30 millimeters, width 15 millimeters.

Genus Glossocarpellites, Gen. Nov.

In the Fourth Vermont Report the species shown on plate 86 as figure 15 and on plate 87 as figures 16 and 17, as well as several other species, were with much hesitation referred to the old genus Carpolithes, to which they had been assigned by Lesquereux. As was noticed in the account given in the report, this genus is so vaguely defined and has been made to include so diverse forms that it is practically of no value. I have therefore created a new genus, to include the very distinctly marked forms shown in the figures above mentioned. It may be characterized as follows:

Genus Glossocarpellites, fruit a carpel, usually of considerable size (25 millimeters or more long), one-celled, walls rather thick, opening on one side by a mucronate, tongue-shaped valve; surface in most species more or less corrugated or furrowed, upper end pointed, lower narrower and rounded. Name suggested by the tongue-like form of the valve.

Professor Knowlton and others have compared these fruits with that of *Jeffersonia diphylla*, but, after careful comparison with quite a number of the fruits of this species, I fail to see much similarity, and certainly not identity of genus. In appearance they resemble the carpels of some species of Banksia, but the opening is somewhat different, and I am quite unable to place these fossils in any of the recent genera.

Glossocarpellites parvus, Perkins.

Carpolithes parvus, Vermont Report, 1903–1904, page 179.

Plate 86, figure 15.

This is much smaller than the other species of this genus. In form it is long ovate, rather thick, so that it is more nearly cylindrical than other species. The valve opens more than half the entire length. Length 21 millimeters, width 12 millimeters, thickness 7 millimeters. This is one of the least abundant forms, only one or two specimens having been found.

Glossocarpellites obtusus (Lesquereux), Perkins.

Carpolithes obtusus (Lesquereux), Perkins, Vermont Report, 1903–1904, page 177.

Carpolithes brandoniana, var *obtusa* Lesquereux, American Journal of Science, volume xxxii, page 356.

Plate 87, figure 16.

This is more broadly ovate than other species, the length and width being about equal. The surface is smoother than in any others of the genus, and on the side opposite to that figured there are 10 or 12 fine grooves extending longitudinally. The opening is only about a third of the length. The lower portion is quite thick and rounded. Length in average specimens 25–30 millimeters, width 25–28 millimeters, thickness at lower end 8–10 millimeters.

Glossocarpellites elongatus (Lesquereux), Perkins.

Carpolithes elongatus (Lesquereux), Perkins, Vermont Report, 1903–1904, page 176.

Carpolithes brandoniana var. *elongata* Lesquereux, American Journal of Science, volume xxxii, page 356.

Plate 87, figure 17.

There are very few of the Brandon fossils as large as this species. It is very long ovate, quite sharply mucronate above, obtusely rounded below, valve opening more than half the length, surface quite rough and irregularly furrowed.

This and the foregoing species are among the most abundant of these fossils. They vary considerably in size. There is a single specimen of this species in the Museum of Comparative Zoology that is 50 millimeters long, but the average specimen is about 35 millimeters long and 20 millimeters wide.

Genus Juglans, Linn.

Juglans brandonianus, Perkins, Vermont Report, 1903–1904, page 182.

Plate 87, figure 21.

This species appears to be a true Juglans. It is one of the larger forms and seems to be well marked. It is somewhat irregularly oval, blunt pointed at the ends, surface irregularly ribbed; length 32 millimeters, width 20 millimeters, thickness 14 millimeters.

Genus MONOCARPELLITES, Perkins, Vermont Report, 1903–1904, page 180.

Monocarpellites gibbosus, Perkins, Vermont Report, 1903–1904, page 181.

Plate 87, figure 18.

Carpel large, flat on the side of one valve, but very gibbous on the opposite side. This surface bears several sharp ridges, as seen in the figure. Upper end mucronate, lower globose. Length 25 millimeters, width 20 millimeters, thickness at lower end 14 millimeters. A cross-section of *Monocarpellites* is shown in figure 28.

Monocarpellites sulcatus, Perkins, Vermont Report, 1903–1904, page 180.

Plate 87, figure 20.

Carpel somewhat irregular in outline, lower portion thick, upper thinner, so that a longitudinal section is wedge-shaped; ribs few; sharp, and prominent; sulci between the ribs wider than in other species, general form round-oval; length 25 millimeters, width 20 millimeters.

Genus TRICARPELLITES, Bowerbank.

Tricarpellites fissilis (Lesquereux), Perkins, Vermont Report, 1903–1904, page 188.

Carpolithes fissilis, Lesquereux, American Journal of Science, volume xxxii, page 356.

Plate 87, figure 19.

Specimens which have been referred to this genus are among the most common in the lignite, and the one figured may be taken as an example of others. Most of these species are large and rather coarse in texture, three-celled and three-valved. The general form is ovate. Like many of these fruits, the upper end is pointed and the lower rounded. In cross-section the fruit is usually strongly three-lobed. Variable in size, but an average specimen is 30 millimeters long, 20 millimeters wide, and 12 millimeters thick.

Genus HICORIA, Rafinesque.

Hicoria biacuminata, Perkins, Vermont Report, 1903–1904, page 193.

Plate 87, figure 22.

This is a very definitely marked and well preserved species. It appears to have the characteristics of the modern genus to which it is referred. It is pointed at each end, quadrangular in section across the middle, irregularly ribbed, surface quite uneven and smooth. Length 25 millimeters, width 20 millimeters, thickness 14 millimeters.

Genus HICOROIDES, Perkins, Vermont Report, 1903–1904, page 183.

There are some fruits which in many respects resemble those of Hicoria, but as there are important differences, it has seemed best to make the above genus to include them. They are not large, none being above medium size. The general form is triangular, pointed above; one side is nearly flat, the other more or less convex, often strongly so; open by a single valve, which is usually on the flat side, but in some it is on the convex side. The surface is ribbed with thin, sharp elevations extending from end to end. In most cases the width is greater than the length.

Hicoroides ellipsoidea, Perkins, Vermont Report, 1903–1904, page 184.

Plate 87, figure 26.

This species is one of the few in which the valve opens on the convex side, as shown in the figure. It is strongly globular or ellipsoidal, longitudinally and irregularly ribbed. Length 20 millimeters, width 23 millimeters, thickness 13 millimeters.

Hicoroides angulata, Perkins, Vermont Report, 1903–1904, page 183.

Plate 87, figure 27.

This species is less globular than the preceding and somewhat smaller. As the figure well shows, the valve is on the flat or, in this case, concave side. The opposite surface is evenly and plainly ribbed. One edge, the right hand in the figure, is much thicker than the other and otherwise unlike it. Length 20 millimeters, width 20 millimeters.

Genus BRANDONIA, Perkins, Vermont Report, 1903–1904, page 192.

This genus has been created to include certain specimens which seem to be quite different from most of those found in the lignite.

Brandonia globulus, Perkins, Vermont Report, 1903–1904, page 192.

Plate 87, figure 23.

This appears to have been of a spongy texture. There is no central cavity evident. In fact it is not unlike some of the globular galls so often found on oak leaves, and further study may show it to be of this nature rather than a fruit. It has become irregular in drying, but it is globular in form, with a diameter of 22 millimeters.

Genus CINNAMOMUM, Blum.

Cinnamomum lignitum, Perkins, Vermont Report, 1903–1904, page 200.

Plate 87, figure 24. (Enlarged three times.)

This is one of the smallest of the Brandon fossils. It is a very pretty little species, especially when magnified. It is very regular in form, which is ovate, surface furrowed with fine but distinct longitudinal and somewhat sinuous grooves, lower end blunt, pointed up, with a very distinctly cupped scar where it was attached. Length 10 millimeters, diameter 6 millimeters.

Genus DRUPA, Gop.

Drupa rhabdosperma, Lesquereux, American Journal of Science, volume xxxii, page 360.

Plate 87, figure 25. (Enlarged five times.)

This is the most ornate of these fossils, and when sufficiently magnified is seen to be elegantly marked over the entire surface with strongly defined corrugations. Only the outer shell has been preserved, as all the specimens are hollow. This outer coating is hard and rather thick. The upper end is beaked, and below the beak is a large triangular scar or, in some cases, opening, lower end regularly rounded. The specimens, of which a considerable number have been found, do not any of them seem to be compressed or in any way distorted. The size is variable, but an average specimen is 5 millimeters long and 3 millimeters in diameter.

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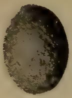
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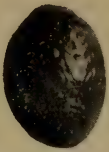
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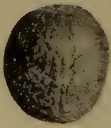
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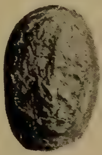
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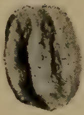
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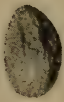
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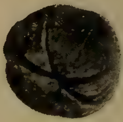
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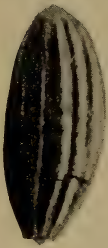
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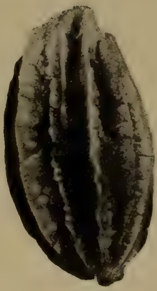
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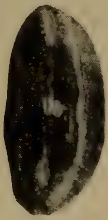
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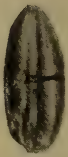
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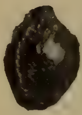
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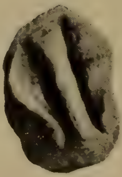
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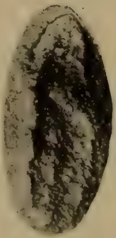
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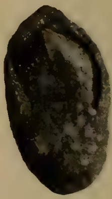
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FOSSILS OF THE LIGNITE OF BRANDON, VERMONT

Explanation of Plates

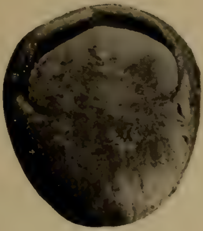
The names of the fossils figured on plates 86 and 87 are as follows:

Plate 86

Figure 1. *Sapindoides medius*, Perkins.
Figure 2. *Sapindoides varius*, Perkins.
Figure 3. *Sapindoides americanus*, Lesquereux.
Figure 4. *Aristolochites majus*, Perkins.
Figure 5. *Aristolochites sulcatus*, Perkins.
Figure 6. *Aristolochites elegans*, Perkins.
Figure 7. *Apeibopsis gaudinii*, Lesquereux.
Figure 8. *Nyssa jonessi*, Perkins.
Figure 9. *Nyssa lescurii*, C. H. Hitchcock. (Enlarged about twice.)
Figure 10. *Nyssa lamellosa*, Perkins.
Figure 11. *Nyssa crassicostata*, Perkins. (Enlarged one and one-half times.)
Figure 12. *Prunoides seelyi*, Perkins.
Figure 13. *Bicarpellites knowltonii*, Perkins.
Figure 14. *Bicarpellites rugosus*, Perkins.
Figure 15. *Glossocarpellites parvus*, Perkins.

Plate 87

Figure 16. *Glossocarpellites obtusus* (Lesq.), Perkins.
Figure 17. *Glossocarpellites elongatus* (Lesq.), Perkins.
Figure 18. *Monocarpellites gibbosus*, Perkins.
Figure 19. *Tracarpellites fissilis*, Lesquereux.
Figure 20. *Monocarpellites sulcatus*, Perkins.
Figure 21. *Juglans brandonianus*, Perkins.
Figure 22. *Hicoria biacuminata*, Perkins.
Figure 23. *Brandonia globulus*, Perkins.
Figure 24. *Cinnamomum lignitum*, Perkins. (Enlarged three times.)
Figure 25. *Drupa rhabdosperma*, Lesquereux. (Enlarged five times.)
Figure 26. *Hicoroides ellipsoideus*, Perkins.
Figure 27. *Hicoroides angulata*, Perkins.
Figure 28. Cross-section of Monocarpellites.
Figure 29. Cross-section of Bicarpellites.



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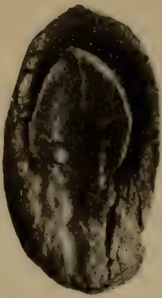

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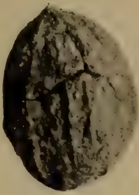

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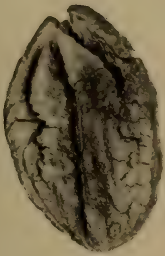

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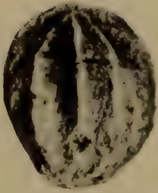

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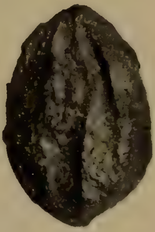

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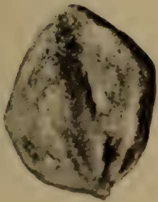

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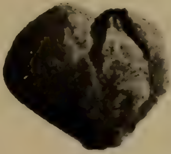

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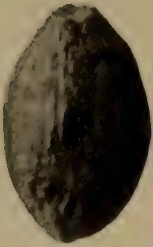

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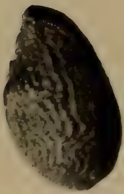

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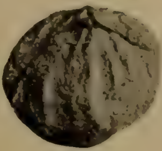

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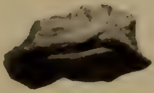

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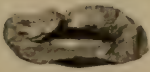

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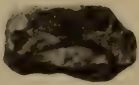

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FOSSILS OF THE LIGNITE OF BRANDON, VERMONT

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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STRATIGRAPHY OF THE UINTA MOUNTAINS

BY CHARLES P. BERKEY

(*Read before the Society Saturday, December 31, 1904*)

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INTRODUCTION

The summer season of 1903 was spent by the writer in the Uinta Indian reservation, which includes the southern flank of the Uinta Mountain range. Many expeditions were made through the western portion of the area. The notes made at that time furnish the data for the following descriptions of local structural features, as well as the basis of the writer's presentation of the accompanying discussion.

EARLY DESCRIPTIONS

The geology of the Uinta region is known almost exclusively through the writings of Clarence King,* S. F. Emmons,† and J. W. Powell.‡ In the matter of stratigraphic succession and equivalence in particular there is considerable divergence of opinion, represented by Major Powell on one hand and the Fortieth Parallel geologists on the other.

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*Clarence King: Paleozoic subdivisions of the fortieth parallel. Am. Jour. Sci., 3d series, vol. xi, 1876, pp. 475-482.

Clarence King: Uinta and Wasatch ranges. Am. Jour. Sci., 3d series, vol. xi, 1876, p. 494.

†S. F. Emmons: U. S. Geological Explorations of the Fortieth Parallel, vol. ii, chapters ii and iii, 1877.

‡J. W. Powell: Geology of the Uinta mountains. 1876.

J. W. Powell: Uinta mountains. Am. Jour. Sci., 3d series, vol. xii, p. 414.

STRATIGRAPHIC PROBLEMS

From the foregoing it will be seen that there are two well marked structural and stratigraphic problems set before the student of the Uinta region :

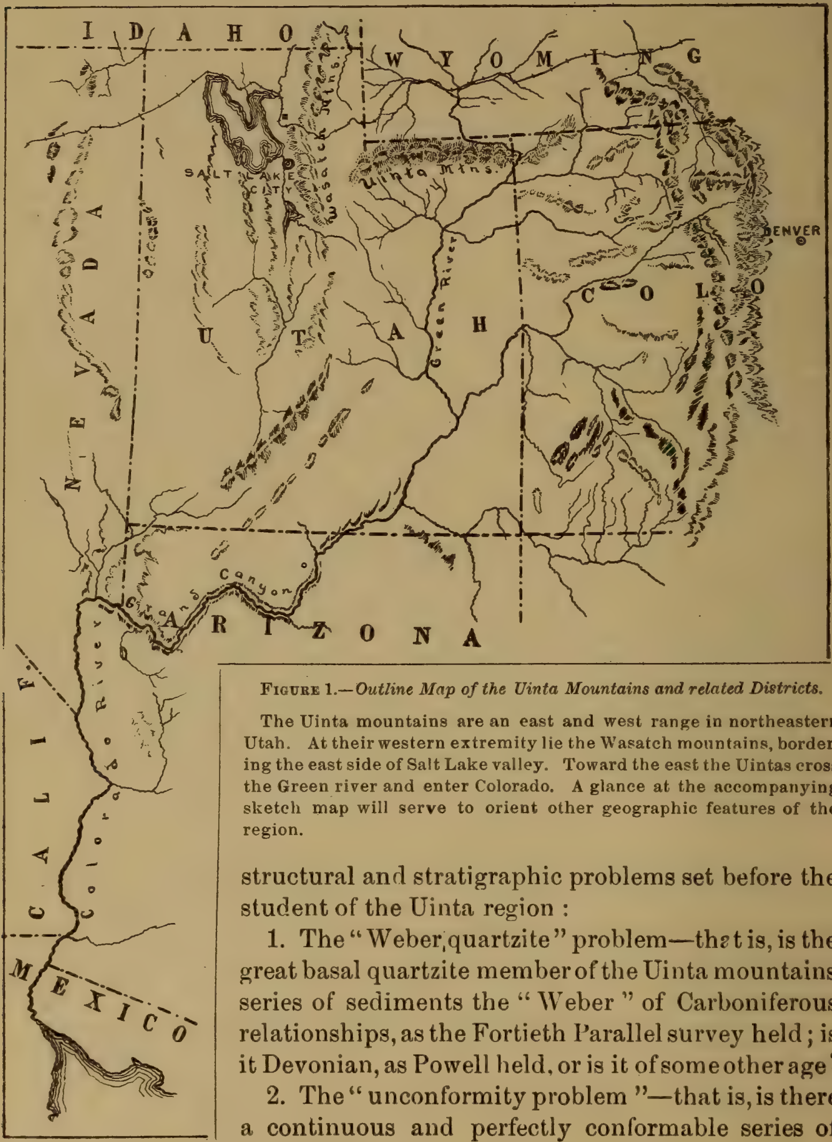

FIGURE 1.—*Outline Map of the Uinta Mountains and related Districts.*

The Uinta mountains are an east and west range in northeastern Utah. At their western extremity lie the Wasatch mountains, bordering the east side of Salt Lake valley. Toward the east the Uintas cross the Green river and enter Colorado. A glance at the accompanying sketch map will serve to orient other geographic features of the region.

1. The "Weber quartzite" problem—that is, is the great basal quartzite member of the Uinta mountains series of sediments the "Weber" of Carboniferous relationships, as the Fortieth Parallel survey held; is it Devonian, as Powell held, or is it of some other age?
2. The "unconformity problem"—that is, is there a continuous and perfectly conformable series of

Paleozoic sediments in this region 20,000 to 30,000 feet thick, followed by an immense thickness of Mesozoic in like position, or is there somewhere a break, and how much does it affect the correlation involved in the first problem?

Others have occasionally touched these questions in their pursuit of related investigations—among them Marsh,* Dutton,† Eldredge,‡ White,§ and Boutwell‖—but so far as the writer knows, nothing has been published to date that even tends toward a settlement of the problems.

Any change in the assumed position of the great basal quartzite in the geologic scale involves a rearrangement of more than half of the total Paleozoic section for the Uintas. A good idea of the extent of the sediments in question may be shown by the following quotation from King:¶

> "In the Wasatch it [the "Weber"] attains a thickness of 6,000 feet, in the Oquirrh, 8,000 feet, and in middle Nevada probably considerably greater thickness. If we are right in assigning the great sandstone series of the Uintas to this member it would have there its maximum development, reaching, according to our observations, 12,000 feet, or 14,000 feet as developed in cañon sections observed by Powell."

King** states one of the points at issue as fully as need be and as clearly as it can be made:

> "Between the 'Weber quartzite' and the upper Coal Measure limestone in the Great Basin and in the Wasatch there is no question of an absolute conformity. In the region of the Uintas, between Professor Powell and ourselves, there is a difference of opinion as to this relation. Powell holds that, although they are conformable in angle, he has discovered an unconformity of erosion, meaning by that that the surface of the sandstone series had been eroded into hills and bluffs, over which, with no difference of angle, the limestone beds were deposited. Having frequently examined the Uinta throughout its whole length, we are of the opinion that this unconformity is illusory, and that the apparent discrepancies can be accounted for by the effects of perspective in observing the outcrops, and by the wonderful series of faults which accompany the Uinta uplift, often bringing the upper limestones down into contact with the quartzites far below the top of the latter series."

On the one hand, after studying the magnificent plates of Powell in his Geology of the Eastern Uintas, one is loath to believe that he was so badly mistaken; while on the other, realizing the exceptional facilities for observation throughout the whole region enjoyed by the Fortieth Parallel geologists, one is equally cautious about neglecting their opinion.

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* On the geology of the eastern Uinta mountains. Am. Jour. Sci., 1871.

† Dutton: The high plateaus of Utah.

‡ Eldredge: Asphalt and bituminous rock deposits. Twenty-second Ann. Rep. U. S. Geol. Surevy, part i.

§ White: U. S. Geol. Survey, Ninth Ann. Rept., pp. 687-688, 1889.

‖ Boutwell: U. S. Geol. Survey Bull. 225, pp. 221-228, 1904.

¶ Clarence King: U. S. Geological Exploration of the Fortieth Parallel, vol. i, p. 240.

** Fortieth Parallel Survey Report, vol. i, p. 241-242.

The Fortieth Parallel geologists' discussion of the stratigraphy of the Uintas is based largely on the Wasatch section, while Major Powell's is based chiefly on the Grand Canyon succession.

The western Uintas

The writer's most systematic field observations relate to the western Uintas. The area most studied is the vicinity of the headwaters of the Du Chesne river and its upper tributaries. It is believed that the discrepancies apparent in this intermediate field, instead of adding to the confusion, really point to a reasonable interpretation of the correlation of the whole series.

The accompanying observations are therefore offered as additional evidence to be used in settlement of disputed questions, or at least as an aid to further work in this field.

Standard Section—the Wasatch Column

The standard section for comparison and correlation is that given in the Fortieth Parallel Survey reports for the Wasatch. It will be necessary to refer to this so often that a condensed table is inserted here.

The Wasatch Column

	Formation.	Thickness.	Description.
Permic.		*Feet.* 500	Argillaceous and calcareous shales, limestones, and sandstones.
Carbonic.		2,000 to 2,500	Limestones, cherts, and shales. Coal Measure fossils from top to bottom.
	"Weber" quartzite.	6,000	Quartzites extremely variable, red sandstones at base, shales, and conglomerates.
	"Wasatch" limestone.	7,000	Coal Measure fossils 4,000 feet. Heavy bedded gray limestone.
Devonic.	"Ogden" quartzite.	1,000 to 1,600	Quartzites with abundant smooth rounded pebbles, conglomeratic.
Siluric.	"Ute" limestone.	1,000 to 2,000	Limestone.
Cambric.		75 12,000	Argillites and shales, micaceous toward top. Quartzites and interspersed slates.
		1,000	Schists and argillites.

As a basis for comparison and discussion, the chief relevant points in the geology of the western Uintas are given below. The accompanying detailed map of the headwaters of the Du Chesne (figure 2) is based on the topographic sheets of the United States Geological Survey, with some minor details added from personal observation.

THE STRATIGRAPHIC SERIES

1. There are no formations exposed below the great sandstone and quartzite series forming the core of the mountain range; but this formation is very thick, perhaps 12,000 to 14,000 feet, as estimated by the early investigators. Neither its upper nor its lower beds are to be seen in this area. A great fault paralleling the range cuts the quartzites abruptly, and from this fault southward the succession of younger strata is continuous. Furthermore, the lowest of them is very suggestive in connection with the question of correlation at issue. The fact that they are not seriously regarded in former discussions would seem to indicate that they do not appear in other areas because of the general faulting; or it may be that, being mainly offshore deposits, they are represented elsewhere by equivalents of very different character.

2. The beds next to the fault line are black pyritiferous shales. They are well exposed at the mouth of Iron creek. Their thickness is unknown.

3. On these shales lie brown, shaly sandstones, calcareous shales, and sandstones which, with the pyritiferous shales, make a total thickness of about 3,000 feet.

4. Next above is a very coarse pebbly sandstone or conglomeratic quartzite less than 1,000 feet thick. Numbers 2, 3, and 4* are non-fossiliferous.

5. A great limestone formation is well marked throughout the Uintas. It is dense and recrystallized into a marble toward the base, but is close grained, bluish, and fossil-bearing in the middle and upper zones. It passes in its upper third into calcareous, argillaceous, and sandy shales and is capped by a limestone that is very cherty. The shales carry abundant fossils of Carboniferous types.

There is a break, discussed in a later paragraph, between this and the succeeding formation.

6. A basal conglomerate merging into a quartzite and shaly sandstone 1,000 feet.

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* All of these beds are non-fossiliferous, and, although they are so well developed, seem to have been largely neglected in the interpretation of stratigraphy. The general statement is made by the Fortieth Parallel reports that the basal quartzite of the Uintas is succeeded by gray limestone, calcareous sand rock, thin calcareous shale beds, and cherty limestone, fossiliferous from bottom to top.

7. Calcareous sandstones, shaly sandstones, limetones, and cherty dolomitic limestones, estimated at approximately 2,000 feet, close the Paleozoic series.

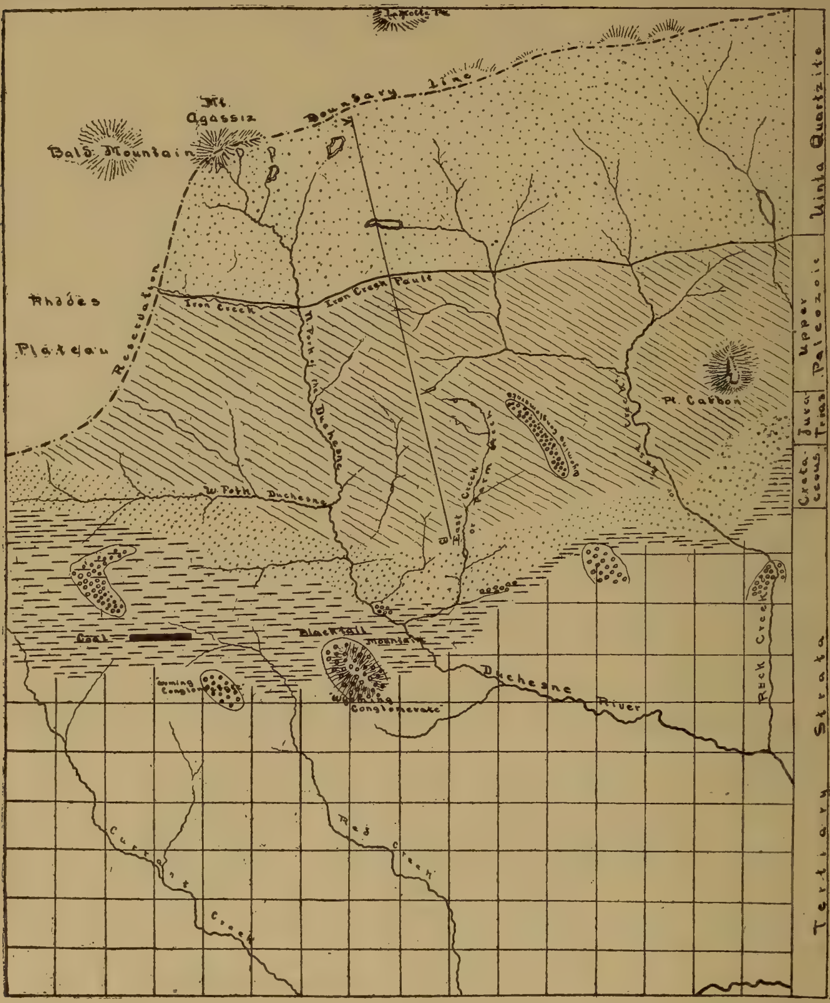
Bald Mountain
Mt. Agassiz
Boundary line
Reservation
Rhodes Plateau
Iron Creek
Iron Creek Fault
N. Fork of the Duchesne
W. Fork Duchesne
East or Bear Creek
Rock Creek
Pt. Carbon
Coal
Blacktail Mountain
"Wyoming Conglomerate"
"Wyoming Conglomerate"
Duchesne River
Current Creek
Red Creek
Uinta Quartzite
Upper Paleozoic
Jura Trias
Cretaceous
Tertiary Strata

FIGURE 2.—*Map of Region about the Headwaters of Du Chesne River.*

Showing approximate boundaries of the formations involved in the fault and flexure of the southern flanks of the western Uintas.

8. The Mesozoic formations of the Triassic, Jurassic, and Cretaceous, of great thickness, follow in apparent conformity.

9. On these formations in turn lie the Tertiary strata in a typical progressive, overlap unconformity, which culminates in conglomerate

cappings of the upturned, eroded edges of the older formations in many isolated patches. These relationships may be seen in the accompanying map (figure 2).

Faulting on the southern Flank

The most persistent and important fault of the south flank of the Uintas, as noted above, crosses the east fork of the Du Chesne at the first western tributary—a small creek locally called Iron creek. The Iron Creek fault strikes east and west, and is strictly, in all this immediate district, the dividing line between the great basal quartzite of the Uinta mountains (King's "Weber") and the shales, sandstones, and limestones of the later Paleozoic. The basal quartzite is not in sight below the shales in ascending the stream to the fault zone, then suddenly it appears as the only rock even to the heights of the adjacent mountain divides. A throw of at least 3,000 feet is therefore measurable at this point, since the difference in altitude between the gorges and the ridges either side is at least that amount. On the plateau between the Du Chesne and Rock creek, locally called "The Old man," this displacement of the strata presents the phenomenon of bringing two prominent quartzite beds together—that is, the basal (first) quartzite north of the fault and the conglomeratic (second) quartzite lying immediately below the gray limestone beds. On this plateau one may easily overlook the break entirely, as the formation seems to be continuous, but in the adjacent gorges the fault shows plainly. It seems possible that this rather unusual juxtaposition[*] of the quartzites may account for the neglect of 3,000 feet of shaly members of the series lying in this V-shaped area in the river valleys.

Toward the east the major fault line cuts higher up in the series, at least above the carboniferous. There are other smaller faults and shattered zones along which there has been vertical displacement. One case of faulting noted by Powell[†] on the north side of the range showed a displacement of 20,000 feet. It is estimated that the folding and associated faulting has resulted in a total elevation of these sedimentary rocks, forming the central portion of the Uintas, to approximately 30,000 feet above their former level. Later erosion has removed 15,000 to 20,000 feet of this and redeposited it along the flanks and in adjacent basins forming all the later rocks.

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[*] On page 146 of volume i and page 313 of volume ii, Fortieth Parallel Reports, several fossils gathered from the drab limestone of "Rhodes' spur" are noted in the following words: "From the base of the formation, not far above the Weber beds, were obtained *Chonetes granulifera*, *Martinia lineata*, *Syringopora*, *multattenuata*, Zaphrentis, Lithostrotion, Enomphalus." When it is pointed out that this is the very region where more than 3,000 feet of strata are in sight below the "drab limestone," and that their contact with the so-called "Weber" in turn is a fault line of unknown displacement' the phrase "not far above the Weber" would seem to insist too strongly on the unity of these formations.

[†] J. W. Powell: Types of orographic structure. Am. Jour. Sci., vol. xii, p. 414. U.S. Geological and Geographical Survey, vol. vii.

UNCONFORMITY

An erosion unconformity occurs in the upper carboniferous beds in this western Uinta region. Evidence is not readily detected along the usual lines of travel, but in no less than four somewhat out-of-the-way places the break is well marked. It may be seen in the vicinity of the forks of the Du Chesne river, just above the massive and cherty limestone member, and is succeeded by the last heavy third quartzite formation of the Paleozoic series. The conglomerate was noted on Farm creek, Rock creek, and Rhodes plateau. Where best exposed, at the headwaters of Farm creek, the upper margin of the gray limestone is very uneven and carries a great quantity of chert—often more than 50 per cent of the whole rock. In addition to the unevenness of this formation, whose billowy outline is not followed by the overlying laminations, the two are not everywhere conformable in angle. There is discrepancy in dip and strike of the two beds, the limestone being more steeply inclined and less uniform.

The base of the overlying formation, chiefly quartzite, is a true basal conglomerate. There are abundant fragments and pebbles and boulders from the cherty limestone bed immediately below, and in some places the finer cementing or filling matter is calcareous rock flour (calcilutyte) and granular limestone (calcarenyte) and chert (silicarenyte).

Fossils are very abundant below the break, but rare above it in this area. From the above it is certain that there is an erosion unconformity in the Upper Carboniferous of the Uintas that marks a moderate readjustment of levels, so that the strata are not perfectly conformable in angle, although the later folding of the range has been so much more profound that this is lost sight of except along the

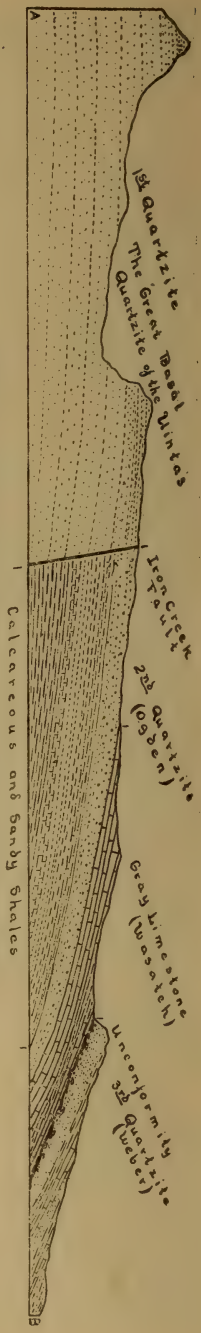

FIGURE 3.—*Generalized Cross-section of the south Flank of the western Uintas.*
Showing succession of formations and the chief fault and unconformity.

immediate break. It marks a time interval also of sufficient length for the consolidation of the rock and the development of a cherty facies, thus converting the cherts and other rock of the floor into suitable materials for succeeding accumulations.

S. F. Emmons* describes a conglomerate of uncertain relationship in the region just north of La Motte peak, a locality on the north flank of the Uinta range directly opposite that studied by the writer. It was described as apparently conformable to the underlying Upper Carboniferous limestone which dips away at an angle of 52 degrees. The occurrence, as the only one observed in the Upper Coal Measure group, was explained as possibly a relic of the Tertiaries or the Wyoming conglomerate and therefore belonging to the latest formations of the region. The writer has not seen this case, but he is of the opinion that if the conglomerate is essentially conformable to the limestone and tilted at such an angle, there is much doubt about it being Wyoming conglomerate for the reason that this rock, being the latest formation of the area, is seldom tilted at all. The discovery, therefore, of a Carboniferous conglomerate on the southern flank would lead one to expect the same relationship in the La Motte Peak occurrence.

Discussion

Only at one point do the pre-Cambrian rocks project up into the great quartzite formation of the Uintas enough to be seen. This was noted by Powell† and by King and S. F. Emmons,‡ who used the name "Red Creek quartzite" for the underlying formation and regarded it as Algonkian in age. The contact is considered the mark of a great erosion unconformity.

There are no traces at any point of limestones or shales below the great quartzite similar to the Silurian, Devonian, and Lower Carboniferous formations, such as lie below the true "Weber" in the typical Wasatch section. If the great quartzite is "Weber," then clearly there is no pre-Weber in that particular part of the Uintas, and a break more profound than even Major Powell claimed would have to be admitted; for in that case the 12,000 feet of Cambrian, the 2,000 feet of Silurian, the 1,000 feet of Devonian, and the 7,000 feet of Lower Carboniferous strata so well marked in the Wasatch must be considered as wanting in the eastern Uintas.

On the other hand if the hiatus is to be regarded as strictly local in the vicinity of this baraboo of Red Creek quartzite, then one is to expect, as King did, that all these enumerated formations do lie buried beneath the great quartzite.

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* U. S. Geological Exploration of the Fortieth Parallel, vol. ii, p. 324.

† Geology of the Eastern Uinta Mountains, 1876, p. 145.

‡ U. S. Geological Exploration of the Fortieth Parallel, vol. ii, pp. 198, 268-269.

Again, if the Uinta basal member is the true "Weber," then all known Paleozoic beds have greatly thickened in passing eastward from the Wasatch as a standard. The 6,000-foot Weber has become from 10,000 to 14,000 feet thick. The 2,000 feet of Carboniferous post-Weber shales and limestones have become 5,000 to 6,000 feet of shales, quartzites, conglomerates, limestones, and sandstones. While if the pre-Weber formations may be assumed to have maintained nearly their normal thickness, and may be counted as present underneath the exposed beds, then we should be confronted with a probable thickness of 20,000 to 25,000 feet of Carboniferous, including one erosion interval in the Uinta mountains—a very extraordinary formation, to say the least. Besides, it would make still more difficult an explanation of the "Red Creek" baraboo by enormously increasing its abruptness and its great height above the old floor, a range of 20,000 to 25,000 feet. It would seem more promising to try the evidence along a different line. Instead of thickening formations, all persisting eastward, may they not rather be thinning and pinching out under ordinary overlap conditions? Such behavior, in view of the comparatively small development of the whole Paleozoic still farther east in Colorado and Wyoming, as low as 1,200 feet, and its entire absence in certain areas farther southeastward, is consistent with much local evidence.

It is worth noting in this connection that the pre-Carboniferous strata in central Colorado* amount to only from 300 to 800 feet.

The thickest bed of quartzite in the Wasatch is given as 12,000 feet, and belongs clearly to the Cambrian, at least in its upper part. A similar thickness of the same formation might be expected in the Uintas, and if the great basal quartzite is placed here the comparison is not only satisfactory as to thickness, but also as to general character of rock. Both are dense, hard quartzites, with occasional shale layers—sometimes red in color and often striped, usually showing massive bedding structures. This similarity was noted by Emmons,† who says "the lower beds of this group (the Uinta quartzites) resemble perhaps the Cambrian rather than the Weber quartzite of the Wasatch." Later, in a footnote, recognizing the unconformity described by Powell, the Cambrian age of these quartzites is further emphasized.

In a later article‡ Mr Emmons even suggests the Algonkian age of the Uinta sandstones, basing this conclusion upon the investigations of Mr Walcott in the Big Cottonwood region.

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*U. S. Geological Survey Folio 48, Ten-mile quadrangle, Colorado; U. S. Geological Survey Folio 9, Anthracite-crested Butte quadrangle, Colorado.

†U. S. Geological Exploration of the Fortieth Parallel, vol. ii, p. 199.

‡Emmons: Orographic movements of the Rocky mountains. Bull. Geol. Soc. Am., vol. i, p. 258.

Another point in the evidence is the existence of the above-described unconformity in the midst of the Carboniferous. Its presence, whether marking a great interval or a comparatively short one, nevertheless lengthens Carboniferous time by just so much. The facts as already stated seem to the writer to argue a considerable time break. The effect is to increase the improbability of such immense thickness of Carboniferous strata. It is recalled here that Powell considered the break in the eastern Uintas one of considerable time value, and notes that the break increases toward the southeast.

There is no evidence either for or against an uncomformity between the basal quartzite and succeeding formations on the south flank in the western Uintas, since the contact there is marked by a fault whose throw of probably several thousand feet brings later shales and quartzites squarely against the basal member.

Emmons' remarks of the Fortieth Parallel region that both limestones and shales become increasingly silicious toward the east.* This is consistent with the idea that a land area lay eastward, and one should expect a rather complete change in the nature of corresponding beds in that direction, with possible thinning and occasional actual breaks in the succession.

If the pre-Paleozoic floor may be assumed to rise toward the east and the Paleozoic sea has encroached on it from the west or northwest, then we should expect equivalent beds of somewhat unlike lithologic character in widely separated areas. Limestones of the Wasatch might correspond to shales in the Uintas, sandstones to conglomerates, shales to sandstones, and in local oscillations some beds might be entirely missing.

In the Wasatch the "Weber quartzite" is both preceded and followed by limestones that are highly fossiliferous and upper Carboniferous in age.

In the Uintas there are no Paleozoic sediments found preceding the basal quartzite, and the description of the later formations varies for different parts of the region. Powell gives 4,000 feet of limestones and shales and sandstones partly fossiliferous, but with the lowest member of his series (the Ladose group) missing in the southeast. Emmons gives gray limestone, calcareous sandstone, and cherty limestone as the general succession. The writer has found in the western Uintas 3,000 feet of shales and sandstones and as much more of quartzites and limestones above the basal member—only the upper members being fossiliferous.

The Weber of the Wasatch is the last great quartzite of the Paleozoic series. In the western Uintas there are two strongly developed quartzites above the so-called Weber. Barring discrepancies in thickness and noting only the succession, the uppermost one of these would appear to correspond fairly well to the true " Weber." As the erosion break occurs here at its base, a sufficient cause for its limited development is at hand; and in point of association with the fossil-bearing strata such correlation seems to the writer more satisfactory, since it avoids the introduction of 12,000 to 16,000 feet of unfossiliferous strata in the midst of the Upper Carboniferous series.

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* U. S. Geological Exploration of the Fortieth Parallel, vol. ii, p. 199.

In the Wasatch the Carboniferous strata, with the exception of the Weber, are very fossiliferous, especially the upper members. In the Uintas there are unfossiliferous beds to the thickness of from 3,000 to 4,000 feet overlying the so-called Weber before coming to the marked fossil-bearing belt.

In this connection there is a very suggestive statement made by Emmons in his discussion of the western Uintas. After giving the list of fossils found on Rhodes plateau, in the immediate region under discussion, attention is called to the fact that out of the seven species enumerated two seem to indicate Lower rather than Upper Coal Measure group *—that is, elsewhere they are found only below the Weber. It would then be all the more remarkable to find them here 15,000 feet above their usual horizon.

Mr Boutwell † also reports the finding of three lots of fossils from this limestone. The fossils were determined by Doctor Girty to belong to the lower Carboniferous (Mississippian). Although Mr Boutwell does not mention the fault or the intervening beds between the limestones and the quartzite, he says "it would appear that the great sandstone series is earlier than the lower Carboniferous."

The quartzite body has furnished no fossils. Three loose fragments ‡ found by the Fortieth Parallel survey were assumed to come from that formation, but as has been pointed out, there are three other quartzites in the Uintas either of which could as well carry fossils. The writer found a spirifer in a loose fragment of quartzite clearly from the uppermost (third) quartzite above the unconformity. It is his conviction, after seeing these different quartzites many times, that residuary fragments of the upper formations might, in spite of all the erosional activity of the region, still lie far within their present limits on the broad anticline of older rocks, and that there is not necessarily enough lithologic difference in

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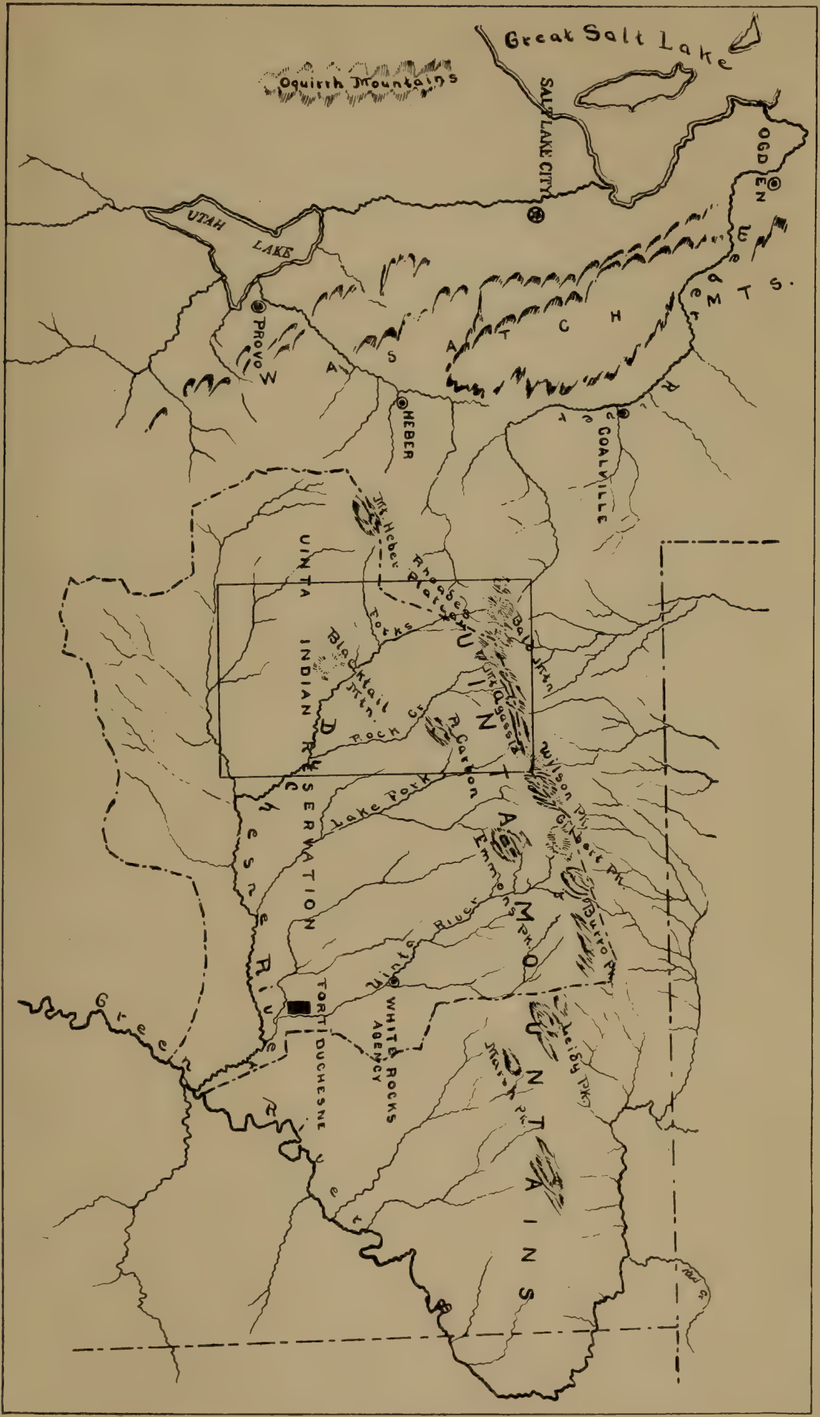
* U. S. Geological Exploration of the Fortieth Parallel, vol. ii, p. 313.

† U. S. Geological Survey, Bull. 225, p. 224, 1904.

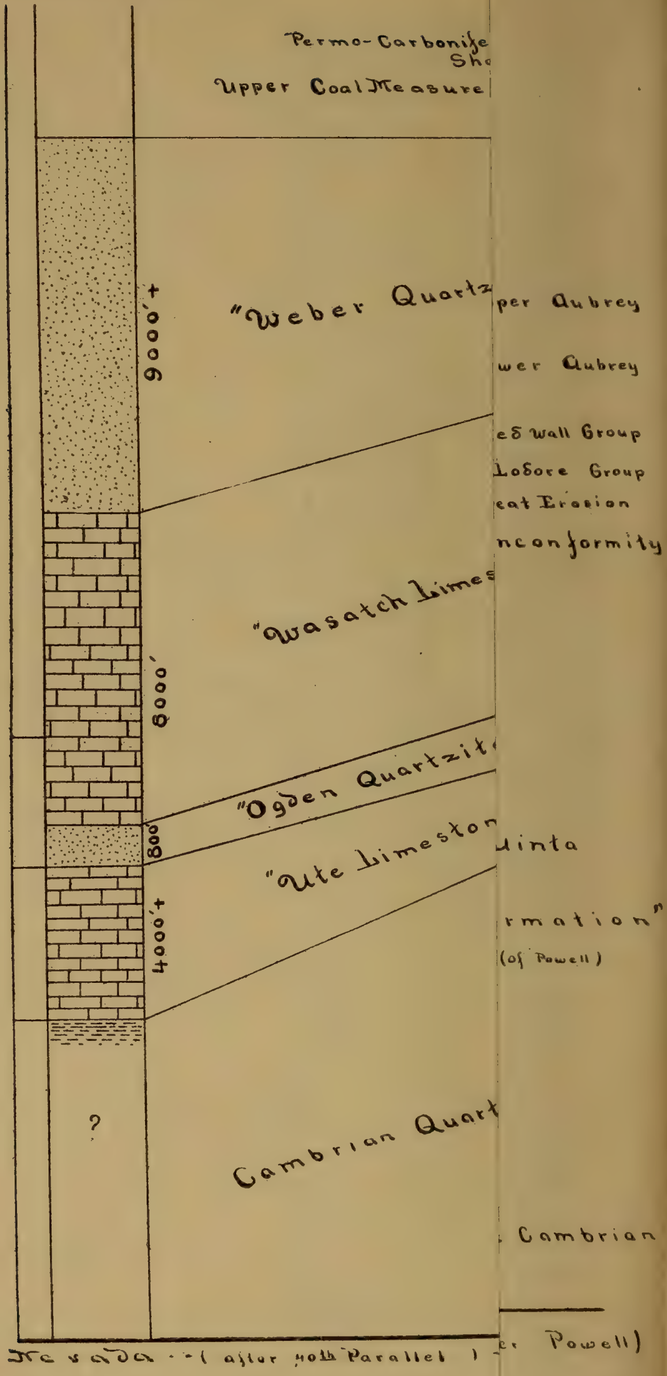
‡ U. S. Geological Exploration of the Fortieth Parallel, vol. ii, p. 290.

U. S. Geological Exploration of the Fortieth Parallel, vol. i, p. 152.


Great Salt Lake
Oquirrh Mountains
SALT LAKE CITY
OGDEN
UTAH LAKE
PROVO
WASATCH MTS.
HEBER
COALVILLE
Weber R.
Mt. Heber
UINTA INDIAN RESERVATION
Rhoades Plateau
Forks
Blacktail Mtn.
Bald Mtn.
Mt. Agassiz
Rock Cr.
R. Carson
UINTA MOUNTAINS
Lake Fork
Wilson Pk.
Gilbert Pk.
Emmons Pk.
Burro Pk.
Uinta River
WHITE ROCKS AGENCY
FORT DUCHESNE
Duchesne River
Green River
Leidy Pk.
Marsh Pk.

GENERAL MAP OF NORTHEASTERN UTAH FROM WASATCH MOUNTAINS TO GREEN RIVER

Showing location of areas involved.


"Permo-Carbonife
Sha
Upper Coal Measure
9000'+
"Weber Quartz
per Aubrey
wer Aubrey
ed Wall Group
Lodore Group
eat Erosion
nconformity
"Wasatch Limes
8000'
"Ogden Quartzit
800'
"Ute Limeston
Uinta
rmation"
(of Powell)
4000'+
?
Cambrian Quart
Cambrian
er Powell)
Nevada -- (after 40th Parallel) -

The connecting lines are inte

small fragments of the different quartzites to satisfactorily trace the origin of a loose piece.

Suggested Correlation

In accord with this view of the stratigraphic relations, the following correlation is suggested:

The basal quartzite (Cambrian) of the Wasatch is still a basal quartzite in the Uintas.

The "Ute limestone" (Silurian) appears eastward as shales—the pyritiferous, black, and other shales of Iron creek—Iron Creek shales.

The "Ogden quartzite" (Devonian) is represented by a quartzite of precisely the type described in the Wasatch, even to the intermixture of rounded and polished pebbles.

The "Wasatch limestone" is much reduced and is represented by heavy limestone at the base, a series of shales in the middle, and cherty limestone followed by an erosion interval at the top.

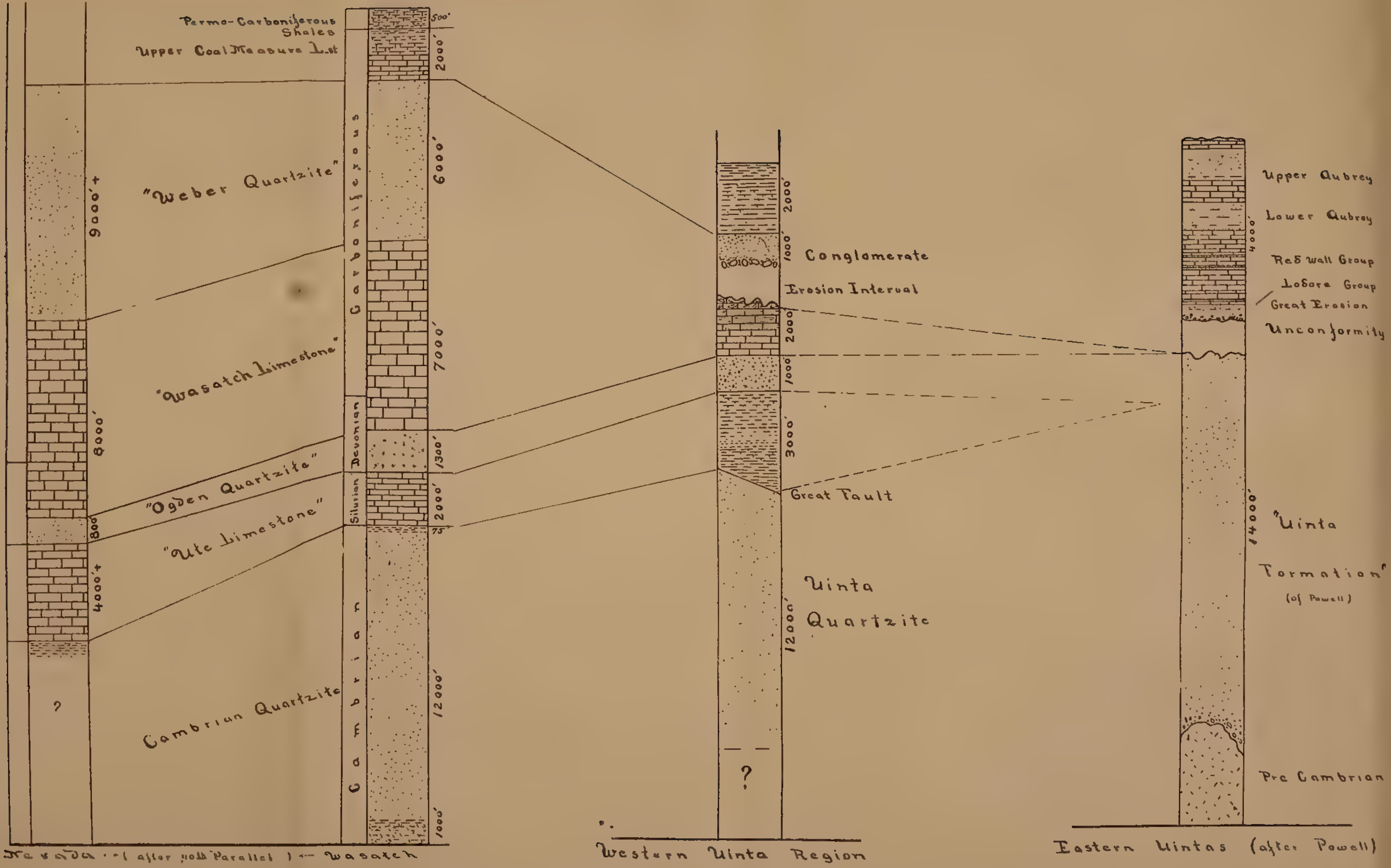
The "Weber" is also greatly reduced. In part it is represented by the erosion unconformity and its upper portion by 1,000 to 1,500 feet of quartzite.

A generalized diagram suggesting this relationship is attempted in plate 88.

With this interpretation of relations the apparent discrepancy in stratigraphic position of the unconformities noted in the two districts (Powell's eastern Uinta and the writer's western Uinta) is conceivable as one and the same; for it is believed that the basal sandstone rises in the geologic scale eastward, so that its upper margin may not represent the Cambrian there as it does in the Wasatch, but may be much later. Allowing then for a withdrawal of the sea slowly westward to and beyond the area studied by the writer and a more rapid readvance to its former boundaries, it is conceivable that the missing interval in the Green River region may be equivalent to not only the interval itself, 50 miles farther west, but also to some thickness of sediments both above and below.

The accompanying chart of geologic sections for the Wasatch, western Uintas, and eastern Uintas, drawn approximately to scale, exhibits more concisely the views outlined in this article.

In conclusion, one is obliged to regret that not only in the first attempt, but in every subsequent one, made at correlation of these formations, there has been insufficient organic evidence to close the argument from that additional side; but this is sure to be found sooner or later. The loss of a considerable collection of fossils from the formations under discussion in the common accidents and limitations of field transportation is a great handicap to the writer. Without the material as evidence,


Permo-Carboniferous Shales
Upper Coal Measure L.st
500'
2000'
"Weber Quartzite"
9000'+
6000'
Carboniferous
"Wasatch Limestone"
7000'
8000'
Devonian
1300'
"Ogden Quartzite"
800'
Silurian
2000'
75'
"Ute Limestone"
4000'+
Cambrian Quartzite
Cambrian
12000'
1000'
?
Nevada --(after 40th Parallel) ← Wasatch
2000'
1000'
Conglomerate
Erosion Interval
2000'
1000'
3000'
Great Fault
Uinta Quartzite
12000'
?
Western Uinta Region
Upper Aubrey
Lower Aubrey
4000'
Red wall Group
Lodore Group
Great Erosion
Unconformity
"Uinta Formation" (of Powell)
14000'
Pre Cambrian
Eastern Uintas (after Powell)

SECTIONS INDICATING THE DEVELOPMENT OF PALEOZOIC STRATA IN NEVADA AND THE WASATCH UPLIFT

The connecting lines are intended to represent the correlation of formations presented in this paper for the western Uintas, and suggest the possible eastward-lying equivalents and overlap conditions

it is useless to take up that line of argument. The writer feels justified on the other grounds to present the above tabulated correlation as exhibiting the best explanation of the known facts of stratigraphy in the western Uinta mountains. It is to be regretted that the use of the term Uinta for Tertiary beds in the same region makes its adoption objectionable.

The existence of two well marked beds of quartzite above the great basal quartzite member, the barrenness in fossils of the first 3,000 feet above it, the existence of an erosion interval and unconformity in the Carboniferous itself, and, after making allowance for the hiatus, the close correspondence lithologically between the Uinta strata and those of the Wasatch from bottom to top, with no radical departure from the succession of the formations, all point to the same conclusion. At least no discussion of Uinta stratigraphy can afford to neglect the above structural features. The fact that some of them have been overlooked or undervalued is the writer's excuse for raising so large a question upon examination of so very limited field.

The basal quartzite of the western Uintas is surely not " *Weber*." It is apparently late Cambrian and possibly in part post-Cambrian lapping up against the margins of the Paleozoic continent toward the east.

It should have been known by the name that Powell gave it—that is, the " Uinta formation " or Uinta quartzite—in preference to any other.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 16, PP. 531-636, PLS. 90-94   FEBRUARY 10, 1906

PROCEEDINGS OF THE SEVENTEENTH ANNUAL MEETING, HELD AT PHILADELPHIA, PENNSYLVANIA, DECEMBER 29, 30, AND 31, 1904, INCLUDING PROCEEDINGS OF THE SIXTH ANNUAL MEETING OF THE CORDILLERAN SECTION, HELD AT BERKELEY, CALIFORNIA, DECEMBER 30 AND 31, 1904

HERMAN LE ROY FAIRCHILD, *Secretary*

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SESSION OF THURSDAY, DECEMBER 29

The Society was called to order by the President, John C. Branner, at 9.30 o'clock a m, in room 116, the Geological Museum and Lecture room, of College Hall, University of Pennsylvania, where all of the sessions of the meeting were held except the evening session of this day.

The report of the Council was called for and was presented by the Secretary, in print, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Seventeenth Annual Meeting Assembled:

The Council has held only one meeting during the year, in conjunction with the meeting of the Society at Saint Louis. Some business has been transacted by correspondence.

The rules relating to publications have been modified, the most important change being reduction of the price of Bulletin brochures. The reduction amounts to 20 per cent of the former prices to Fellows and 40 per cent of the prices to the public. The amended rules and the Constitution and By-Laws with changes to date are published as the closing pages of Bulletin, volume 15.

In all respects the affairs of the Society continue in a highly satisfactory condition, as shown in the following reports of officers, which give the details of administration for the sixteenth year in the life of the Society.

Secretary's Report

To the Council of the Geological Society of America :

Meetings.—The record of the Saint Louis meeting will be found in the closing brochure of Bulletin, volume 15.

With the change by the American Association for the Advancement of Science from summer to winter meetings, it becomes desirable to remove our consitutional requirement which compels summer meetings in conjunction with the Association.

Membership.—Since the last printing of the List of Fellows the names of four Fellows have been taken from the list by death—C. E. Beecher, J. B. Hatcher, Henry McCalley, and W. H. Pettee. The names of eleven new Fellows have been added to the list and one removed by resignation. This makes the present enrollment 259, or six more than at the last printing. Fifteen nominations are now before the Society, and several candidates are awaiting action by the Council.

Distribution of Bulletin.—At this date 448 pages of volume 15 of the Bulletin have been distributed, and the remaining brochures are in hand, awaiting the completion of the Proceedings brochure for final mailing. The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 15; sold to Fellows, 2. Brochures sent to supply deficiencies, 32; sold to the public, 10; sold to Fellows, 15; sent in exchange for other brochures, 32. One copy of volume 14 has been donated and three copies bound for use of the officers and the Library.

The sale during the past year of back volumes to the Fellows has been very small. As a complete set of the published volumes, including the 10-volume index, now costs the Fellows $64.75, newly elected Fellows can not be expected to purchase them. Only one complete set has been sold the past year to libraries. Future demands for sets will be largely supplied by sets offered for sale from libraries of deceased Fellows. Our future sale of the Bulletin will be chiefly of current volumes.

Bulletin sales.—Receipts from sale of the Bulletin during the past year appear in the following table :

Receipts from Sale of Bulletin, December 1, 1903, to December 1, 1904

	Complete volumes.			Brochures.			Grand total.
	Public.	Fellows.	Total.	Public.	Fellows.	Total.	
Volume 1..	$5 00	$4 50	$9 50	$1 60	....	$1 60	$11 10
Volume 2..	10 00	4 50	14 50	....	$0 40	40	14 90
Volume 3..	10 00	....	10 00	....	45	45	10 45
Volume 4..	5 00	....	5 00	....	....	....	5 00
Volume 5..	5 00	....	5 00	....	20	20	5 20
Volume 6..	5 00	....	5 00	....	....	....	5 00
Volume 7..	5 00	....	5 00	3 00	1 25	4 25	9 25
Volume 8..	5 00	....	5 00	....	30	30	5 30
Volume 9..	5 00	....	5 00	....	2 65	2 65	7 65
Volume 10..	5 00	....	5 00	60	....	60	5 60
Volume 11..	5 00	....	5 00	70	....	70	5 70
Volume 12..	....	....	....	....	....	....	....
Volume 13..	5 00	....	5 00	2 80	6 79	9 59	14 59
Volume 14..	260 00	....	260 00	3 90	1 35	5 25	265 25
Volume 15..	185 00	....	185 00	40	....	40	185 40
Volume 16..	25 00	....	25 00	....	....	....	25 00
	$540 00	$9 00	$549 00	$13 00	$13 39	$26 39	$575 39
Index......	2 50	....	....	....	....	....	2 50
	$542 50	$9 00	$551 50	$13 00	$13 39	$26 39	$577 89

Receipts for the fiscal year...............................	$577 89
Previous receipts, to November 30, 1903....................	7,577 08
Total receipts to date.....................................	$8,154 97
Charged and uncollected....................................	32 32
Total Bulletin sales to date...............................	$8,187 29

Bills have not been sent to regular subscribers for volume 15.

Exchanges.—The exchange list includes one more than last year, and the Committee on Exchanges will recommend a few additions and omissions.

Expenses.—The following table gives the cost of administration and Bulletin distribution from the Secretary's office during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1904

Account of Administration

Postage and telegrams..	$20 90	
Expressage...	2 84	
Printing (including stationery)..............................	112 40	
Meetings (not included in printing)..........................	24 60	
Total..		$160 74

Account of Bulletin

Postage	$126 50	
Expressage and freight	53 53	
Wrapping material (envelopes, &c.)	1 05	
Address links	1 94	
Binding three copies volume 14	3 00	
Purchase of brochures to fill deficiencies	3 00	
Collection of checks	4 00	
Total		$193 02
Total expenses for the year		$353 76

Respectfully submitted.

H. L. Fairchild,
Secretary.

Rochester, N. Y., *December 10, 1904.*

Treasurer's Report

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the fiscal year ending December 1, 1904.

Ten (10) Fellows remain delinquent for two years, while twenty-six (26) are delinquent for this year.

Five (5) Fellows—G. D. Harris, R. R. Hice, R. S. Tarr, E. O. Ulrich and F. E. Wright—have enrolled for life by the payment of the one-hundred-dollar fee, thus increasing the total number of Life Commutations to sixty-eight (68).

The $1,000 bond of Tioga township, Neosha county, Kansas, was called for redemption, without any knowledge of the Treasurer, in 1903, and hence, when the interest coupon due February 1, 1904, was forwarded to New York for collection, the fiscal agency of the state of Kansas declined to pay the interest and replied that the bond would be paid on presentation. As there was no provision for redemption on the face of the bond prior to maturity in 1916, and as Treasurer Williams (H. S.) had purchased the same at a considerable premium, in the belief that it could not be redeemed before the date mentioned on the face of the bond, the Treasurer declined to accept the terms offered. The attorney for Tioga township claimed the legal right to redeem the bond under a general statute of the state providing for such redemptions before maturity, and after the Treasurer had contested his views in a lengthy correspondence (which is submitted to Council herewith), a compromise was effected, in which the township paid the deferred interest coupon and redeemed the bond at $1,081.80 on April 1, 1904. The terms of this compromise were submitted to Dr H. S. Williams, First Vice-President of the Society, the acting President during the absence of Doctor

Branner in Europe, and he fully sustained the views of the Treasurer in advising the acceptance of the same rather than a resort to the courts, in which the costs, even if successful, would have much exceeded the amount involved.

With the receipts from this redemption and several fees for life commutations the Treasurer had more funds than seemed advisable to retain in bank at only 4 per cent interest; so, in concurrence with Doctor Walcott and Doctor Emmons, the two other members of the Committee on Investments, the Treasurer purchased on April 11, 1904, three (3) $1,000 second mortgage 5 per cent bonds of the United States Steel Corporation at 78⅞ net, or $2,366.25, which yield an annual interest return of $150 in two payments (May 1 and November 1), or a little more than 6⅓ per cent on the amount invested. These bonds are now (December 20, 1904) quoted at 92¼, and if the Council does not approve of the investment in this class of securities, which yield the higher rate of interest, the bonds can be sold at a profit to the Society and the proceeds reinvested in any other securities which Council may prefer. At the time of purchase these were the only bonds available which appeared to be reasonably safe and would yield 6 per cent interest on the investment.

The interest item from all sources ($576.98) has thus been considerably increased over that ($328) for last year by this increase in the invested funds from $6,300 to $8,300.

On Account of Publication Fund

The securities now owned by the Society (all of which are deposited in the fire and burglar proof vaults of the Bank of the Monongahela Valley at Morgantown, West Virginia) are as follows:

March 17 and 25, 1898, two Texas Pacific Railroad first mortgage 5 per cent bonds, cost $1,976.25	$2,000
February 6, 1901, 10 shares of the capital stock of the Iowa Apartment House Company, Washington, D. C.	1,000
April 1, 1903, 20 shares of the capital stock of the Ontario Apartment House Company, cost $2,000	2,000
May 5 and September 27, 1895, 3 first mortgage 6 per cent bonds of the Kingwood, Tunnelton and Fairchance railroad, cost $304	300
April 11, 1904, 3 second mortgage 5 per cent bonds, United States Steel Corporation, cost $2,366.25	3,000
Total cost, $7,646.50; total par value	$8,300

The Texas Pacific and United States Steel bonds are quoted on the New York Exchange at 119¼ and 92¼, respectively, on December 20, 1904.

The general financial condition of the Society, as shown by the receipts and disbursements for the past year, is exhibited in the following tabular statement.

Statement of Receipts and Expenditures

RECEIPTS.

Balance in treasury December 1, 1903			$3,031 79
Fellowship fees 1901 (1)	$10 00		
" " 1902 (7)	70 00		
" " 1903 (24)	240 00		
" " 1904 (157)	1,570 00		
" " 1905 (1)	10 00		
		$1,900 00	
Initiation fees (11)		110 00	
Life commutations (5)		500 00	
Interest on investments:			
Iowa Apartment House Co. stock	$60 00		
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00		
Tioga Township, Kansas, bonds	35 00		
Ontario Apartment House Co. stock	120 00		
Texas and Pacific R. R. bonds	100 00		
U. S. Steel Corporation bonds	150 00		
Interest on deposits with Security Trust Company	93 98		
		576 98	
Redemption of bonds:			
Tioga Township, Kansas, bond and premium, redeemed		1,081 80	
Sales of publications		577 89	
			4,746 67
Total amount of receipts (carried forward)			$7,778 46

Total receipts brought forward			$7,778 46

EXPENDITURES.

Secretary's office:			
Administration	$160 74		
Bulletin	193 02		
Allowance (traveling and clerical expenses)	500 00		
		$853 76	
Treasurer's office:			
Postage	$15 00		
Expressage	1 88		
		16 88	
Librarian's office		7 66	
Photographic account		15 00	
Publication of Bulletin:			
Printing	$1,851 79		
Engraving	443 44		
Editor's allowance, personal and office expenses	250 00		
		2,545 23	
Investments		2,366 25	
Total expenditures to December 1, 1904			5,804 78
Balance in treasury December 1, 1904			$1,973 68

Respectfully submitted.

I. C. White,
Treasurer.

Morgantown, W. Va., *December 22, 1904.*

EDITOR'S REPORT

To the Council of the Geological Society of America:

The Editor is particularly glad to be able to state that through the coöperation of the members it has been possible to complete volume 15 before the winter meeting of the Society. This desirable result can always be accomplished if contributors will be prompt in forwarding their papers and in returning proof.

Though volume 15 is unusually large and surpasses its predecessor in size, it is less voluminously illustrated. It contains 636 pages of text and has 59 half-tone plates and 16 line drawings. There has been a noticeable tendency to increase the size and the illustrative material of later volumes. The average number of pages of the first ten volumes was 544 and of plates 26, while volumes 11 to 15, inclusive, have an average of 603 pages and 57 plates. There has been in consequence an increase in cost of publication, but the average per page has been very slight. The cost of volume 15 is given below and a tabulated comparison made with the average cost of the first ten volumes and the individual cost of volumes 11, 12, 13, and 14.

	Average. Vols. 1–10.	Vol. 11.	Vol. 12.	Vol. 13.	Vol. 14.	Vol. 15.
	pp. 544. pls. 26.	pp. 651. pls. 58.	pp. 538. pls. 45.	pp. 583. pls. 58.	pp. 609. pls. 65.	pp. 636. pls 59.
Letter-press	$1,465 14	$1,815 56	$1,445 73	$1,647 12	$1,657 50	$1,661 21
Illustrations	200 40	373 68	414 80	477 27	431 21	457 76
	$1,665 54	$2,189 24	$1,860 53	$2,124 39	$2,088 71	$2,118 97
Average per page	$3 23	$3 36	$3 45	$3 64	$3 43	$3 33

The following is a reasonably correct analysis of the contents of volumes 7 to 15, inclusive:

Divisions.	*Vol. 7, Pages.*	*Vol. 8, Pages.*	*Vol. 9, Pages.*	*Vol. 10, Pages.*	*Vol. 11, Pages.*	*Vol. 12, Pages.*	*Vol. 13, Pages.*	*Vol. 14, Pages.*	*Vol. 15, Pages.*
Areal geology	38	34	2	35	65	199	125	48	115
Dynamic geology	3	24	85	24	110	23	17	47	9
Economic geology	4	14	16	28	7	5	4	1	3
Glacial geology	5	98	138	96	21	55	1	48	48
Historical	..	..	..	16	46	..	24	1	52
Memoirs	28	8	12	27	60	2	32	14	18
Official matter	56	69	54	72	59	58	153	68	63
Paleontology	123	58	64	68	188	5	42	22	1
Petrology	40	43	44	59	54	24	28	183	7
Pysiographic geology	53	5	..	37	10	53	24	59	54
Geology and pedagogy	12	..	..	..	..	..	..	..	..
Rock decomposition	74	26	17	9	..	16	..	..	..
Stratigraphic geology	21	67	28	62	31	98	116	118	266
Terminology	1	..	..	1	..	..	5	..	..
Total	558	446	460	534	651	538	583	609	636

Long experience has convinced the Council that the prices at which the Society's publications have been offered to its Fellows and the public have been too high, and the rates for the brochures of volume 15 have been reduced to cost plus 100 per cent to members and cost plus 200 per cent to the public. The prices are given in each volume in the preliminary matter. In volume 15 they are on pages vii and viii.

Owing to the fact that summer meetings have been abandoned practically, volume 15 begins with the presidential address instead of the proceedings of the summer meeting, as heretofore.

Respectfully submitted.

JOSEPH STANLEY-BROWN,
Editor.

NEW YORK, *December 10, 1904.*

LIBRARIAN'S REPORT

To the Council of the Geological Society of America:

The accessions to the library for the past year have been duly catalogued and acknowledged as received, and the list of accessions up to July 1 has been made out and transmitted for publication in the Bulletin.

The library now comprises some 2,600 numbers, of which 1,400 are bound volumes. Of these 1,200 belong to the continuing sets of publications received as exchanges, the remainder being scattering and individual publications. Some 200 of these volumes were received bound, while the remainder have been bound by the Case Library authorities.

Pamphlets and individual separates make up the remaining numbers, although there are quite a number of maps. None of these have been bound; yet they should be the better to preserve them, and their proper disposal in this respect is a perplexing problem, concerning which the Librarian would be glad to receive suggestions. This is especially the case with the maps. Cleveland is such a smoky city that it is by no means an ideal place in which to keep even bound books, and unbound materials tend to rapid deterioration.

The expenses of this office for the past year are as follows:

To express	$1 50
To postage	1 16
To clerk hire	5 00
	$7 66

Respectfully submitted.

H. P. CUSHING,
Librarian.

CLEVELAND, OHIO, *December 10, 1904.*

On motion of the Secretary, it was voted to defer consideration of the Council report until the following day.

As the Auditing Committee to examine the accounts of the Treasurer, the Society elected J. S. Diller and E. O. Hovey.

ELECTION OF OFFICERS

The result of the balloting for officers for 1905, as canvassed by the Council, was announced by the President, and the officers were declared elected as follows:

President:
Raphael Pumpelly, Dublin, N. H.

First Vice-President:
Samuel Calvin, Iowa City, Iowa.

Second Vice-President:
W. M. Davis, Cambridge, Mass.

Secretary:
H. L. Fairchild, Rochester, N. Y.

Treasurer:
I. C. White, Morgantown, W. Va.

Editor:
J. Stanley-Brown, Cold Spring Harbor, Long Island.

Librarian:
H. P. Cushing, Cleveland, Ohio.

Councillors:
H. M. Ami, Ottawa, Canada.
J. F. Kemp, New York city.

ELECTION OF FELLOWS

The Secretary announced that the candidates for fellowship had received a nearly unanimous vote of the ballots sent, and that Fellows were elected as follows:

Ralph Arnold, Ph. D., Washington, D. C. Geologic Aid, U. S. Geological Survey.

John Adams Bownocker, D. Sc., Columbus, Ohio. Professor of Inorganic Geology, Ohio State University.

Reginald Walter Brock, M. A., Ottawa, Canada. Geologist, Geological Survey Department; Professor of Geology, School of Mining, Kingston.

Nevin Melancthon Fenneman, Ph. D., Madison, Wis. Professor of Geology, University of Wisconsin.

Charles Newton Gould, B. S., A. M., Norman, Okla. Professor of Geology, University of Oklahoma.

Mark S. W. Jefferson, A. M., Ypsilanti, Mich. Professor of Geography, Michigan State Normal College.

Charles E. Beecher

Hiram Deyer McCaskey, B. S., Manilla, P. I. Chief of the Mining Bureau of Manilla.

Benjamin Le Roy Miller, Ph. D., Bryn Mawr, Pa. Associate in Geology, Bryn Mawr College.

Henry Montgomery, Ph. D., Toronto, Canada. Professor of Geology and Biology in Trinity University.

Cleophas Cisney O'Harra, Ph. D., Rapid City, S. Dak. Professor of Mineralogy and Geology, South Dakota School of Mines.

Albert Homer Purdue, B. A., Fayetteville, Ark. Professor of Geology, University of Arkansas.

Arthur Edmund Seaman, B. S., Houghton, Miss. Professor of Mineralogy and Geology, Michigan College of Mines.

Solon Shedd, A. B., Pullman, Wash. Professor of Geology and Mineralogy, Washington Agricultural College.

Bohumil Shimek, C. E., M. S., Iowa City, Iowa. Professor of Physiological Botany, Iowa State University.

Gilbert van Ingen, Princeton, N. J. Curator of Invertebrate Paleontology and Assistant in Geology, Princeton University.

No new business was presented.

The President called for the necrology, and the following memoirs of deceased Fellows were presented.

In the absence of the author, the first memoir was read by H. E. Gregory:

*MEMOIR OF CHARLES EMERSON BEECHER**

BY CHARLES SCHUCHERT

One of America's leading paleontologists, and a Fellow of this Society since 1889, in the fullness of intellectual power, suddenly passed away on February 14, 1904. Few men were better prepared for great results and more promising of them for the next twenty years than Charles E. Beecher. Dall has said:

> "There is no doubt that in the death of Professor Beecher not only has Yale sustained a serious loss and paleontology a severe blow, but the ranks of those capable of bringing to the study of fossils keen insight and a philosophical spirit of enquiry, guided by principles whose value can hardly be exaggerated, are diminished by one whom science could ill afford to lose."

Like most successful students of organic life, Beecher was a born naturalist. As a boy of twelve years he began to make a collection of recent shells and fossils, continuing to add to this for the next thirty years; so that, in 1899, he was able to present to Yale University, "unconditionalally," upward of 100,000 fossils. To the Albany Museum he gave his entire collection of land and fresh-water shells, some 40,000 specimens. In the field few excelled Beecher as a collector. To him more than to any other we owe the present methods of washing clay for immature invertebrates as well as of etching silicious fossils from limestone. The Yale collections are rich in such delicate and well-preserved material. Clarke, who often collected with him, stated that "he was the most discriminating acquirer of the unusual, the exceptional, and the fine that it was my fortune to know."

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*Sketches of Beecher have appeared as follows: Yale Alumni Weekly, March 2, 1904, by Bush, Chittenden, Schuchert, and "a graduate student;" Science, March 18, 1904, by Dall; Amer. Naturalist, June, 1904, by Jackson; Amer. Geologist, July, 1904, by Clarke; Museums Jour., London, April, 1904; Geol. Mag., London, June, 1904, by Woodward.

As a paleontologist he was trained in stratigraphy and in the description of species and genera, but latterly he took almost no direct interest in this kind of work. Often he told me that he wished all our fossils were named. This is all the more remarkable because of his long association with Hall and Marsh. The explanation seems to lie in the fact that his philosophic bent did not come to full fruition until he had personally met the philosophic American paleontologist, Alpheus Hyatt. From that time his mind was absorbed in working out the ontogenetic stages in fossil species and in tracing their genetic sequence through the geological formations. To Beecher we owe the first natural classification of the Brachiopoda and the Trilobita, based on the law of recapitulation and on chronogenesis. He also gave a very philosophic account as to the origin and significance of spines in plants and animals. On these works his reputation in days to come will chiefly rest.

Beecher was not only a born naturalist, but also had much mechanical ability. Nothing pleased him more than to free fossils from the surrounding matrix, and his unexcelled talent in this direction is shown in the preparations of *Triarthrus* and *Trinucleus* in the Yale University museum. More than 500 specimens have been prepared by him, and this work has required peculiar skill, patience, ingenuity, and a great deal of time. It is very unfortunate that he did not live to finish his studies on the trilobites, but he left all the better specimens completely worked out, and of most of them he had made photographs and drawings.

Charles Emerson Beecher, son of Moses and Emily D. Beecher, was born in Dunkirk, New York, October 9, 1856. Not long after this date his parents removed to Warren, Pennsylvania, where he prepared for college at the high school, and was graduated from the University of Michigan, receiving the degree of B. S. in 1878. The ten succeeding years he served as an assistant to Professor James Hall. In 1888 he was invited by Professor Marsh to remove to New Haven and to take charge of the collections of invertebrate fossils in the Peabody Museum. His career as a teacher of geology began in 1891, when for two years he took charge of Dana's classes at Yale, and in 1892 he was made Assistant Professor of Historical Geology in the Sheffield Scientific School, serving in this capacity until 1897, when he became Professor of Historical Geology and a member of the governing board in the Sheffield Scientific School. In 1899 he succeeded the late Professor Marsh as curator of the geological collections, and was made a member of and secretary to the board of trustees of the museum. In 1902 his title was changed to that of University Professor of Paleontology. He was eminently successful as a teacher, both with undergraduates and with advanced students, his enthusiasm and kindliness of character at once arousing their interest and devotion.

Beecher received the degree of Ph. D. from Yale in 1889, his thesis being a memoir on the Ordovician Brachiospongidæ. In 1899 he was elected a member of the National Academy of Sciences and a foreign correspondent of the Geological Society of London. In 1900 he was elected President of the Connecticut Academy of Arts and Sciences, and filled this office for two years. He was also a member of the American Association of Conchologists, Geological Society of Washington, Boston Society of Natural History, and Malacological Society of London.

Some time before Beecher was graduated from the University of Michigan, the desire of his youth to follow as his life's work the study of fossils became a conviction. The year before his graduation he is seen worshipping at the shrine at Albany, where many another paleontologist had preceded him on the same errand. Clarke describes Beecher's introduction at Albany in the following interesting way :

> "On a hot summer day in 1877, pale with weariness, he staggered with pack on back into the laboratory of Professor James Hall at Albany. He had sought what to him had seemed the fountainhead of knowledge of his fossils. It had been the goal of many a youthful dream to show to the author of the *Paleontology of New York* the treasures he had found. The great and keen-eyed Hall ever had an appreciative reception for such endeavor. With the most friendly concern he refreshed and nursed this acolyte, and, when strength had returned, expressed a lively interest in his efforts and his ambitions. On going away Beecher had promised to come back to Albany when his college course was done and join Hall's corps of workers on paleontology. So, in the summer of 1878, the year of his graduation, he became assistant to Professor Hall, entered upon his work, and was received with genuine enthusiasm."

Beginning with the summer of 1880 and continuing into 1883, he read, according to a list still extant, more than 18,000 pages of standard literature. During the 10 years with Hall he assisted very largely in the preparation of the Paleontology of New York, treating of the Lamellibranchiata, Gasteropoda, Cephalopoda, and Bryozoa; and to a less extent on the volumes pertaining to the Pteropoda and corals. These were great days of preparation and they bore most valuable fruit later on.

As to his methods of investigation, Clarke says:

> "A part of Mr Beecher's fine natural equipment for scientific research was his indomitable patience necessary to establish broad premises. His conclusions were never hasty nor ever stated on merely one aspect of the evidence. All the more far-reaching and striking of his deductions in his later work, when his mind had turned chiefly to problems of biogenesis, are known to his friends to be the result of tireless acquisitions of material and the focussing of light from every source. In some quarters, his methods unknown, their results were not accepted; they were regarded as startling, as iconoclastic, and even unreliable."

During his bachelor days at New Haven he lived in "the attic," a series of rooms fitted up in Bohemian style in old Sheffield Hall, with Penfield, Pirsson, and Wells, all of whom are now full professors. After the day's work the "attic philosophers" met here in delightful intercourse, social and scientific, and it was here that during the late '80's and early '90's many pleasant acquaintances and recollections were acquired with the young scientific men of this and other countries.

Beecher's first paleontologic paper was published by the Geological Survey of Pennsylvania in 1884, when he was 28 years old. It treated of new genera and species of Phyllocarida from the Devonian, a group of rare Crustacea, most of which he found about his home. He was always on the lookout for these rare fossils, and after securing many hundred additional specimens he again returned to the subject, and in 1902, in a paper published by the Geological Society of London, embodied all that is known of the Upper Devonian Phyllocarida of Pennsylvania.

Beecher's first turn from stratigraphic paleontology to pure paleobiology and correlation had its origin in the brachiopods. Hall had assembled some tons of the Silurian fossils occurring at Waldron, Indiana. This collection contained many slabs, and as much loose clay adhered to them, Beecher and Clarke night after night for an entire winter washed this material; eventually they together obtained about 50,000 specimens of young brachiopods, among which were included every stage of development of these shells. Their results were published in 1889 in a well-illustrated paper entitled "Development of some Silurian Brachiopods."

From a study of the nature of the pedicle opening, these authors concluded that the "phylogenetic development tended in two main channels," and this arrangement foreshadowed two orders of brachiopods for which Beecher later proposed the names Neotremata and Telotremata.

My acquaintance with Beecher began in 1889, and at that time it was evident that the paper just referred to was being considered with a better understanding of what Hyatt's principles meant when applied to Brachiopoda. The very fact that nearly all the Waldron, Indiana, brachiopods began with smooth shells having a subcircular outline led him to look for this early stage in other genera, but as no other young shells were at hand, he resorted to a study of the beaks in well-preserved examples of mature shells. In the spring of 1891 he announced that he had seen the initial shell in 15 families representing 40 genera.

A study of the stages of growth in many brachiopods, from the Cambrian to the living forms, enabled Beecher to show that the old classifications were not expressive of genetic relationship. He demonstrated that on the basis of types of pedicle openings all brachiopods are naturally grouped into four orders, of which two are without, and two possess hinge teeth. The most primitive order (*Lingula*, etcetera) he named Atremata, and this gave rise directly to the Telotremata (*Rhynchonella*, *Terebratula*, etcetera). The Neotremata (*Crania*, *Discina*, etcetera) also originated in the Atremata, and from the former descended the Protremata (*Strophomena*, *Productus*, etcetera).

In 1893 there was discovered in the Utica formation near Rome, New York, a thin band in which nearly all the trilobites occur as pseudomorphs in iron pyrite and retain antennæ and legs. Trilobites with legs had been known before in two specimens and in four genera. Walcott determined the presence of legs by slicing enrolled individuals. Antennæ, however, had not been clearly made out until 1893, when their presence was announced by Matthew in the August number of the American Journal of Science. This discovery was of great value and promised much toward a better understanding of the ventral anatomy of trilobites and their systematic position among the Crustacea. Beecher was thus led to visit the locality in 1893, when he took out several tons of shale; since then he has published fifteen papers on trilobites. Of these, three are devoted to the larval stages, seven to the ventral anatomy, and five to the classification and systematic position of these forms.

Beecher showed that in *Triarthrus* the entire series of thoracic legs are biramous, one being setæ-bearing and used for swimming and the other without setæ and used for crawling. The limbs of the pygidium overlap each other, are much crowded, and are adapted for swimming or guiding the animal, although they may also have served as egg-carriers. The head has five pairs of appendages, four pairs of which are biramous and closely resemble the thoracic legs.

He also observed that in the first or unsegmented stage of the most primitive trilobites there are neither dorsal free cheeks nor eyes, but that in some of the later forms both the eyes and free cheeks have migrated to the anterior margin or may even have progressed a little posteriorly down the dorsal side of the first or unsegmented stage. This led him to undertake a study of all trilobite genera, more than two hundred in number, and it was seen that these could be arranged in three groups or orders on the basis of the nature and position of the free cheeks. These orders he named Hypoparia, Opisthoparia, and Proparia.

In 1892 he became greatly interested in the significance of spines, accumulating data until 1898, when he presented his studies in a paper entitled "The origin and significance of spines." This paper he regarded as his best and most philosophic work. He found that all kinds of spines in plants and animals can be arranged into eleven distinct categories. Further, that two generalizations result, as follows:

> "That spinosity represents the limit of morphological variation, and, second, that it indicates the decline or paracme of vitality." . . . "Finally it is evident that, after attaining the limit of spine differentiation, spinose organisms leave no descendants, and also that out of spinose types no new types are developed."

Beecher's standing among biologists and paleontologists was high; he was a leader among students of Brachiopoda and Trilobita, and Jackson has said that he "became the leader of the Hyatt school." He had the artist's gift, nearly all the drawings illustrating his various papers being made by himself and exhibiting a high order of merit. He was a slow and very careful worker. Those who knew him well saw in him an enthusiast, but his exuberance was always held in check by his judicial qualities, which also made him an excellent counselor. He was orderly in his work, and, as he had the "museum instinct" well developed, he made one of the best of curators.

In 1894 Beecher married Mary Salome Galligan, of Warren, Pennsylvania, who, with two daughters, survives him. He died very suddenly, of *angina pectoris*, at his home, shortly after 1 o'clock on Sunday afternoon, February 14, 1904. Up to about 11 o'clock of the same day, he was in his usual health. He lies in Grove Street cemetery, in the shadow of the Sheffield Scientific School.

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MEMOIR OF JOHN B. HATCHER[*]

BY W. B. SCOTT

A full account of Mr Hatcher's varied and eventful life would be a fascinating story of adventure, of daring and unconquerable energy, of self-sacrificing devotion to duty, and of single-minded love of science. This story can never be adequately written, for only the hero could have done that; what he might have made of it is indicated by the "Narrative" of his expeditions to Patagonia. In reviewing this work for *Science*, Doctor Dall has said:

> "At times wrapped in gloomy fogs or swept by tempests of incredible violence; fronting the towering Atlantic surges with unshaken cliffs and serrate talus, looking out to shifting bars of sand, the terror of the navigator; a vast cemetery for ghostly herds, upon the like of which alive no man has ever looked; it is a strange, silent, bitter, lonely land.
>
> "How our author went out into it, what he met, and how he fared are told in modest yet most interesting fashion in this stately quarto. His story is so interesting and the unpretentious courage of the narrator so evident, the spirit of the land and its mysterious fascination so fully expressed, that few will close the book without a regret that it can not reach a wider audience. It is really too good to be reserved for the readers of quartos.
>
> "The volume is so full of scientific meat that it is difficult to make a satisfactory abstract and impossible to condense it within the limits of such a review as this. There is something for every taste. The life of bird and beast; the phases and contrasts of vegetation; the life of the Tehuelche Indians and the waifs who have cast civilization aside like a garment at the call of the wild; the topography and geology; and mingled with it all a flavor of real North American character, to which something in each reader's soul will leap with sympathy and admiration."

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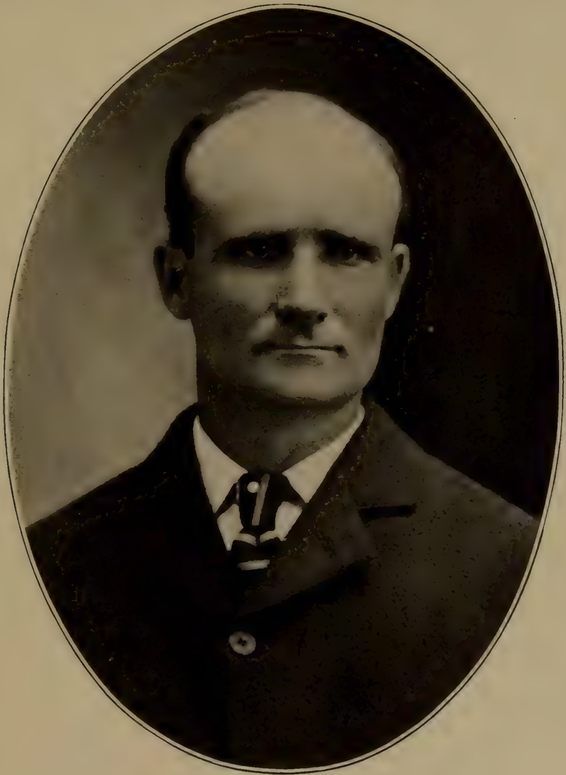
[*] This memoir was not read on account of the absence of the author, but is inserted here in its proper place.



J. B. Hatcher.

While it is now impossible to tell this remarkable story in detail, its principal events may be compressed into a brief statement.

John Bell Hatcher, the son of John and Margaret Hatcher, was born at Cooperstown, Brown county, Illinois, on October 11, 1861, and at a very early age removed with his family to Greene county, Iowa, where he remained till his twentieth year. As a child, he was so weak that his parents could scarcely hope to see him grow to manhood, and his early education was given him by his father, who was a teacher as well as a farmer. Gradually his strength increased, and as he grew older there matured within him a determination to become a thoroughly educated man—a determination which he followed with characteristically persistent energy and scorn of obstacles, however seemingly insuperable. To secure the funds necessary for his education, he became a coal miner, and, being a born observer, the miner's life soon awakened in his mind a great and ever growing interest in geology and in the fossils which he saw around him. It was to follow this early bent that in 1880, after a short stay at Grinnell College, Iowa, he went to Yale University, whither he was especially attracted by the fame of Professor J. D. Dana, whose books he had zealously studied. At New Haven he devoted himself to the natural sciences, more particularly to geology and botany. A collection of Carboniferous fossils, which he had made in his coal-mining days, was the means of introducing him to Professor Marsh, who sent him to the West as a collector immediately after his graduation.

In this connection I may perhaps be permitted to quote what I have elsewhere written:

> "Thus began a career which was unrivaled of its kind, for Hatcher had a positive genius for that particular work, as is well known to all who have had the privilege of accompanying him in the field. Marvelous powers of vision, at once telescopic and microscopic, a dauntless energy and fertility of resource that laughed all obstacles to scorn, and an enthusiastic devotion to his work combined to secure for him a thoroughly well earned success and a high reputation. He may be said to have fairly revolutionized the methods of collecting vertebrate fossils, a work which before his time had been almost wholly in the hands of untrained and unskilled men, but which he converted into a fine art. The exquisitely preserved fossils in American museums, which awaken the admiring envy of European paleontologists, are to a large extent directly or indirectly due to Hatcher's energy and skill and to the large-minded help and advice as to methods and localities which were always at the service of any one who chose to ask for them.
>
> "Hatcher's uprightness and sincerity of character, no less than his remarkable energy and persistence, attracted to him the admiration of many western men, by whom frequent tempting offers were made him to leave the unremunerative paths of science for the material rewards of business; but in vain. He would not seriously consider the abandonment of his chosen work for any reward whatever, and he died in harness."

Of his wonderful activity and success as a collector, Schuchert has remarked:

> "From 1884 to 1892 he sent in nearly 900 boxes of vertebrate material. As a rule, these boxes were of large size, and one exceeded 3 tons in weight. This huge box (about 10 feet long, 5 feet wide, and 6 feet deep), containing the largest known skull of *Triceratops*, had to be lifted out of a ravine 50 feet deep and hauled to the railroad over a trackless country and through streams for more than 40 miles. It is no exaggeration to state that during the 20 years of Hatcher's paleontological activity, he, with the assistance of a few field helpers, sent to the United States National Museum, and to Yale, Princeton, and Carnegie museums not less than 1,500 boxes of fossils. This is a record that will stand unequaled—a work that Hatcher loved—resulting in material part of which he hoped it would be his lot to study. After Marsh's death the uncompleted Ceratopsia volume was assigned to Hatcher by the United States Geological Survey. This gave him great gratification, for he was thus enabled to associate his name, not only as a collector but also as a student, with these great and curious beasts, all of which he had discovered and taken up."

Dr W. J. Holland, director of the Carnegie museum in Pittsburg, has borne similar testimony to Hatcher's work as a collector:

> "Mr Hatcher's position as a paleontologist was unique. He is universally admitted by those most competent to pass judgment to have been the best and most successful paleontological collector whom America has ever produced. In saying this it may at once be admitted that he was in all probability the most successful collector in his chosen domain who has ever lived. Professor Hatcher and those associated with him under his control during the years of his activity in the field assembled more important vertebrate fossils than have been assembled by any other one man whose name is known in the records of paleontology. The larger proportion of the choicest vertebrate fossils now in the Peabody museum at Yale University, in the collection of the United States Geological Survey, in the museum of Princeton University, and in the museum of the Carnegie Institute at Pittsburg were collected by him. To a very large extent the American methods of collecting such remains, which are now universally admitted to be the best methods known, were the product of his experience in the field and of his careful thought. In a letter just received by the writer from Professor Henry Fairfield Osborn, the Paleontologist of the United States Geological Survey, he says, alluding to the death of Professor Hatcher: 'I can hardly tell you how shocked and grieved I am. I had often thought of the probability of Hatcher's death in the field when taking great risks and entirely away from medical and surgical attendance, but of his death at home I had not thought a moment. In his intense enthusiasm for science, and the promotion of geology and paleontology, and the tremendous sacrifices he was prepared to make, and *had made*, he was a truly rare and noble spirit—the sort of man that is vastly appreciated in England and in Germany, but I fear very little appreciated in America. His work as a collector was magnificent—probably the greatest on record.'"

While thus at work as a collector over an enormously wide range of country and through almost the whole geological column from the Permian to the Pleistocene, Hatcher was continually studying the stratigraphy of the beds in which he worked and determining their faunistic divisions and subdivisions. Nor did he neglect the dynamical and structural problems involved in the formation of the successive beds. Not only was he an unusually keen and accurate observer, but he possessed a singularly original and independent mind. He was utterly impatient of authority in science, and to him every theory must be supported by convincing evidence and not merely buttressed by the weight of great names. His untimely death has robbed the world of a rich store of geological knowledge, the publication of which had not fairly begun.

In 1893 Hatcher accepted a call to Princeton University as assistant in geology and curator of vertebrate paleontology in the museum, and with unabated zeal continued his work along much the same lines as before. During the three seasons 1893–1895 he worked in the Uinta, White River, and Loup Fork and Sheridan beds, gathering great quantities of priceless material. On all of these trips he was accompanied by field parties of students, who became his fast friends and ardent admirers; his skill, energy, persistence in the face of difficulty and peril appealed most strongly to their imaginations. On the other hand, he took the warmest interest in his students, especially in those whose education must be gained through their own efforts; with admirable delicacy and tact, he was fertile in devices to enable them to help themselves and thus continue their studies unweighted by any humiliating sense of being the objects of charity.

The most important work that Hatcher undertook during his connection with Princeton, and perhaps the most important enterprise of his whole career, was his exploration of Patagonia in the three expeditions of 1896–1899. The plan and execution of this great work were his own; from his former students he obtained a large part of the necessary funds, to which he generously contributed himself. Indeed, proportionately to his means he was the largest subscriber to the fund. The expeditions, the main object of which was to secure representative collections illustrating the geology and paleontology of Patagonia, were brilliantly successful, and their scope was gradually extended so as to include as well the botany and zoology of the region. To his assistants, Messrs Peterson and Colburn, much credit for the success of the work is due; but the leading spirit was Hatcher's throughout. In his "Narrative," already mentioned, may be found the extremely well written and interesting account of his Patagonian journeys; but, interesting as it is, this book gives to the reader a very imperfect conception of his achievement. Only those who heard his intimate talk and had the pleasure of reading his fascinating letters from the field can understand what were the difficulties and dangers that opposed his advance or can rightly estimate the dauntless courage and unrelenting energy which triumphed over the most formidable obstacles, both material and moral. Wounds and sickness, long weeks of helpless and agonizing pain, hardships of every kind, represent but a few of the difficulties that he met and conquered. In the long and glorious history of scientific exploration there are but few chapters that tell of truer heroism and finer achievement than Hatcher's life in Patagonia.

When all the collections had been brought to Princeton and it was seen what a mass of new and valuable material had been secured, Hatcher conceived the plan of publishing the whole in a uniform series of reports by the ablest specialists who could be induced to cooperate. The only alternative would have been a crowd of more or less fragmentary and uncorrelated papers scattered through many technical journals and proceedings of societies. The liberality of J. Pierpont Morgan, Esq., has made possible the realization of this plan, and the "stately quartos" of the Reports of the Princeton University Expeditions to Patagonia will form a lasting monument to the memory of Hatcher, whose labors and sacrifices they record.

In February, 1900, Hatcher became curator of vertebrate paleontology in the museum of the Carnegie Institute, Pittsburg, a position in which he remained till his death, on July 3, 1904. The same qualities that had distinguished his earlier career continued to make him equal to his new and larger duties and responsibilities. To him especially is due the extremely rapid growth of the Pittsburg collections and their remarkably high quality.

Aside from the desolated household and the circle of bereaved friends, the essential tragedy of Hatcher's early death lies in the fact that his work had just begun. Though best known as a collector and the most skillful and successful of collectors, he was very much more than that. For 20 years he had been giving himself the most thorough training and acquiring an experience of such magnitude and variety as falls to the lot of few geologists. All his previous life had been but the seed time, and just as the harvest was ripe for the sickle, the reaper was stricken down. Owing to a modest self-distrust, his productive period began relatively late, and his first paper was published after his removal to Princeton; but he gradually gained confidence with experience, and had his life been spared he would surely have enriched science with a series of notable contributions. For enthusiastic, self-sacrificing devotion, unconquerable determination, and high achievement, we shall not soon look upon his like again.

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MEMOIR OF HENRY MCCALLEY

BY EUGENE A. SMITH

Henry McCalley, who died of pneumonia in Huntsville, Alabama, on November 21, 1904, was born in that city February 11, 1852. He was the son of Thomas Sanford McCalley, of Spottsylvania county, Virginia, and Caroline, daughter of Robert Landford, who built the second house in Huntsville.

Mr McCalley was one of a family of nine children who reached adult age. He lived at his home, 2 miles west of the court-house in Huntsville, from his birth to manhood. His school career was begun under the care of Mrs McKay, then considered the most excellent teacher for young children. From Mrs McKay he went to Dr J. M. Bannister, rector of the Church of the Nativity, and afterward to the noted Mr Charles Shepard, who is still living and engaged in teaching. At the well known school of Dr Carlos G. Smith he was prepared for college, soon after the end of the civil war. As the University of Alabama was at that time in the hands of the "carpet-baggers" and without students, he went to the University of Virginia, from which institution he was graduated in 1876 with the degrees of Civil Engineer and Mechanical Engineer. At the university he applied himself very closely to his studies, gaining the highest esteem of both professors and students, but sacrificing his health. On his return home after graduation he spent one year on the farm with a view to restoring his health.

With the strong recommendation of the faculty of the University of Virginia, he took charge of a school at Demopolis, Alabama, where he remained one year and part of another. In the summer vacation of 1877 he came to the Geological Survey of Alabama as a volunteer assistant and traveled with the writer through a part of the Warrior coal field and the valley of the Tennessee. The following year, 1878, Mr McCalley gave up his school and came to the University of Alabama as assistant in the department of chemistry, then in charge of the writer of these lines. This position he held until 1883, at the same time also serving as volunteer assistant on the Geological Survey, for during the first ten years of the existence of this second survey the annual appropriation was only $500, none of which went for salaries.

During the summer months of 1879 we had charge of a survey of the Warrior river for the Engineer Office of the War Department, under Major Damrell, the object of which survey was primarily to ascertain the nature and extent of the obstructions to navigation and to obtain estimates of the cost of removing or overcoming the same, and, secondly, to collect statistics of the natural resources of the country lying adjacent to the river.

The levelings and soundings along the river were made under the direction of Mr McCalley, while the geological data were collected by Mr Joseph Squire and myself. Our joint report was published in a Report of Progress for 1879–1880. Later in the year Mr McCalley spent some time in the Tennessee valley, and the results of his labors were given in the same report of progress.

In 1883 the legislature made an appropriation for the Geological Survey which made it possible to employ salaried assistants, and Mr McCalley then received the appointment as assistant state geologist, which position he held until his death, a period of 21 years.

His first work in this capacity was in the Warrior basin, on which his first report was published in 1886. This was the first comprehensive statement of the characters and succession of the coal seams of this great field and it gave great help to those who were engaged in the development of the state. Next he took up the study of the plateau portion of the Warrior field, in northeastern Alabama, and his report on the coal measures of this section was published in 1881.

His next work was in the Paleozoic formations of the Tennessee, Coosa, and other great valleys in which occur the limestones, iron ores, and bauxites of the state, and the results of several years work in this section were published in 1896 and 1897 under the title "The Valley Regions of Alabama," part I being devoted to the valley of the Tennessee and part II to the Coosa and other anticlinal valleys, Cahaba, Wills, Jones, and Blount Springs valleys.

The great activity in coal mining during the 10 years following the publication of the report of 1886 on the Warrior basin rendered necessary a reexamination and more thorough study of the field, and Mr McCalley spent much time in going again over the ground with Mr George N. Brewer as an assistant, and in 1890 appeared his report on the Warrior basin, with a large map.

Since 1900 his work has been in the region of the igneous and metamorphic rocks, upon which he was engaged at the time of his death. Unfortunately his notes on this region were not written up, though quite full and comprehensive. This will make it impossible to get the full benefit of his work.

In personal character Mr McCalley was modest and somewhat retiring, but no one could be more firm and decided than he in the defense of a friend and in the defense of his own opinions on geological matters after he had formed them from his own extended observations. In his scientific work he was careful and painstaking to an extraordinary degree, and his conclusions were rarely hastily formed, and they were in consequence generally correct. He was one of the most truthful of men, and he could be relied upon to do to the best of his ability whatever work was assigned to him. When called upon to give his views he did it with the utmost frankness, swerving neither to the right nor the left from the straight path of truth. In his connection with the Survey he was several times called upon to expose frauds, and, after he had become convinced on thorough examination of the facts, he left those concerned in no doubt as to his conclusions and convictions.

He was a consistent and active member of the Episcopal church and very generous in his support of it, responding cheerfully to all the calls made upon his time and means.

It is said of him that as a child and a young boy he had never received a correction from either parent or teacher and he never neglected a task set before him; these characteristics followed him through life.

Mr McCalley was a member of the American Association for the Advancement of Science; Fellow of the Geological Society of America; member of the American Institute of Mining Engineers; secretary of the Alabama Industrial and Scientific Society, etcetera.

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MEMOIR OF WILLIAM HENRY PETTEE

BY ISRAEL C. RUSSELL

William Henry Pettee was born in Newton Upper Falls, Massachusetts, January 13, 1836, of representative New England parentage. His father was a manufacturer of cotton fabrics and of mill machinery. In boyhood his studious tastes had to be restrained and his college preparation delayed out of regard to his somewhat slender bodily frame. He entered Harvard College at nineteen years of age, took high rank in the required classical course of that period, was selected to deliver a Latin oration in his junior year, and graduated with distinction in the class of 1861. He continued in graduate work in the same university for over three years, receiving the degree of Master of Arts in 1864, studying at first in the engineering department of the Lawrence Scientific School and later in the college, where at the same time he was an assistant.

From 1865 to 1869 he traveled and studied in Europe, his main work being in the Royal Mining Academy of Saxony, at Freiberg, with vacations in the mining regions of Germany.

In 1868 Mr Pettee returned to Harvard University as a teacher in the School of Mining and Practical Geology, then established, under the direction of Josiah D. Whitney. His appointment in 1869 was that of instructor in mining, but in 1871 he was advanced to the rank of assistant professor in the same branch and provision made for work upon geological surveys to be carried on under the auspices of the Harvard School of Mining.

In the summer of 1869 Professor Pettee made a geological and topographical survey of South Park, Colorado, and during the year 1870–1871, having been granted a leave of absence from Harvard, he became connected with the California State Geological Survey. Besides making a study of gold-bearing gravels of California, he undertook systematic work in correction of the determination of altitudes by means of the barometer. Some of the results of this investigation, collected from the detailed reports of the survey, were published by authority of the California state legislature in 1874, entitled "Contributions to Barometric Hypsometry, with Tables for use in California," to which a supplement was added in 1878. Professor Whitney's estimate of the onerous labor, the accuracy, and perseverance of Professor Pettee's work in this undertaking appears in the prefatory note to the volume above mentioned.

From 1871 to 1875, in addition to other duties, Professor Pettee gave instruction to an elective section of undergraduates in physical geography, geology, and meteorology at Harvard; but before 1875 the conditions of the gift supporting a school of mining at that institution were altered and provision for a special instructor in these subjects was withdrawn.

In 1875 Professor Pettee was appointed to a professorship of mining engineering and related subjects in the University of Michigan, a position which he held with various changes of title until his death.

In the first semester of 1879–1880 Professor Pettee was granted leave of absence from the University of Michigan to continue his investigation of the auriferous gravels of California. His report on that work was published as an appendix to the first volume of Whitney's "Contributions to American Geology." It has been adjudged to show that careful examination of phenomena, weighing of evidence, and painstaking accuracy, which those best acquainted with Professor Pettee always expect in papers prepared by his hand.

The annual Transactions of the American Institute of Mining Engineers have been submitted to Professor Pettee for many years for critical proofreading and correction. Of that society he was a life member, his election dating from 1871. For many years he was a coworker with its secretary, Rossiter W. Raymond, who, in a recent memorial published in the Transactions of the Institute, expressed high appreciation of Professor Pettee's ability as a literary critic. He was one of the original fellows of the Geological Society of America, a fellow of the American Association for the Advancement of Science, in which he was general secretary in 1887; a member of the American Academy of Arts and Sciences during his residence in Massachusetts, and a member of the American Philosophical Society of Philadelphia.

For Professor Pettee the members of the faculty of the University of Michigan, of which he was a member for twenty-nine years, hold only memories of the highest respect and the warmest friendship. These cherished sentiments are but a reflection of his own genial and loving nature, left by him as an inheritance to all with whom he came in contact. His more pronounced characteristics as revealed in his intercourse with his colleagues, whether personally and socially or in connection with official duties, and equally conspicuous to the students who received his instruction, were a kindly and loving nature, patience under difficulties, painstaking accuracy in all of his work, love of truth, and unswerving uprightness of character. With these high ideals were coupled an abundant and ever accessible knowledge of the history and traditions of education in Michigan and a love for the branches of science to which he devoted his time and energy.

Professor Pettee died at his home in Ann Arbor, Michigan, on May 26, 1904. While his chief work during life was that of a teacher, his few contributions to geology and kindred subjects show that he was a painstaking and accurate observer.

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1879. Report on an examination of portions of the gravel mining regions of California, in Placer, Nevada, Yuba, Sierra, Plumas, and Butte counties, made in 1879. Forms appendix A, pp. 379–487, of The auriferous gravels of the Sierra Nevada of California, vol. 1, Contributions to American geology, by Whitney, Harvard College, Museum of Comparative Zoölogy, memoirs, vol. 6, Cambridge, 1880.

In the absence of the author the following memoir was presented in abstract by Professor A. P. Brown, University of Pennsylvania:

MEMOIR OF CHARLES SCHAEFFER

BY ANGELO HEILPRIN

In the death of Dr Charles Schaeffer, which took place on November 24, 1903, the friends of science have lost a genial and most lovable associate, and one who, while not professionally nor professedly a naturalist, was to that extent interested in the beauties and workings of nature as to consider the field of inquiry of the naturalist as his own by association. A love for flowers, a discriminating eye for minerals, and an unusually skillful hand in the manipulation of the camera, brought to Doctor Schaeffer a many-sided nature, which years of pleasurable travel, with a loving wife for helpmate, broadened out into what are still to many "pastures new."

Most of Doctor Schaeffer's observations were given by word of mouth to his associates, and only exceptionally were they published in paper form. He was a member of numerous scientific societies: American Philosophical Society, Academy of Natural Sciences of Philadelphia, Geological Society of America, Franklin Institute, Geographical Society of Philadelphia, American Association for the Advancement of Science, Pennsylvania State Medical Society, Philadelphia County Medical Society, College of Physicians of Philadelphia, Historical Society of Pennsylvania, Photographic Society of Philadelphia, Horticultural Society of Pennsylvania, etcetera. His closest association was with the Academy of Natural Sciences of Philadelphia, to whose body of members he was elected in 1861, and in which he served for long terms of years on the Council and as Recorder to the Botanical, the Biological, and the Mineralogical and Geological sections. For many of the later years of his life Doctor Schaeffer made the Canadian Rocky mountains and the Selkirks his summer abode, drawing from them a wealth of new information and imparting to others through his collections charming lessons of the region which he could almost justly call his own. The little colony of Philadelphians who year after year return to Glacier House or thereabout to make observations on glacial phenomena or mountain structures, and on the habits, colors, and distribution of the Canadian sub-Alpine floras, have been pioneered to their camps by Doctor Schaeffer, who sought in the mountain air the new vigor of life.

Doctor Schaeffer's name will be fittingly perpetuated in a sumptuously illustrated volume on the flowering plants of the Canadian Rocky mountains—the work, artistically and otherwise, principally of Mrs Schæffer—now in course of preparation.

Following the reading of the memoirs, the Secretary made announcements concerning matters of business and the program, and Mr N. H. Darton, Committee on Photographs, announced that the collection of photographs was displayed in an adjoining room.

The President declared the scientific program in order. The first paper presented was the following:

DEVELOPMENT AND MORPHOLOGY OF FENESTELLA

BY EDGAR R. CUMINGS

[*Abstract*]

Thin sections and serial sections of exceptionally well preserved bases of *Fenestella* (*semicoscinium* of authors) from the Hamilton of Thedford, Ontario, show the exact size and shape of the primary zoœcium (*Protœcium*) and the morphology and orientation of the primary buds. The protœcium consists of an elongate tubular zoœcium with a large basal disk. It is without hemisepta. Morphologically, it is strictly comparable to the protœcium of Cyclostomata (of *Tubulipora*, *Lichenopora*, etcetera). The two primary buds arise from the dorsal face of the protœcium, usually just above the basal disk, and are very symmetrically orientated with reference to the dorso-ventral plane. They are of about the same shape as the protœcium and somewhat smaller. Each of these buds produces a single bud in the first tier, and an additional bud arising from one of the latter completes the first tier of buds—six zoœcia, including the protœcium. Zoœcia of the shape characteristic of the adult *Fenestella* colony do not appear till the colony begins to branch. Hemisepta have not been seen in any of the earlier zoœcia. These studies seem to definitely relate *Fenestella* genetically to the Cyclostomata. The Cyclostomata are therefore the ancestors of the Cryptostomata and through them of the Chilostomata.

Remarks on the paper were made by H. M. Ami. It is printed in full in the American Journal of Science, volume xx, pages 169–177.

The second paper was

BEARING OF SOME NEW PALEONTOLOGIC FACTS ON NOMENCLATURE AND CLASSIFICATION OF SEDIMENTARY FORMATIONS

BY HENRY SHALER WILLIAMS

The paper was discussed by the President, H. M. Ami, I. C. White, N. H. Darton, A. C. Lane, D. W. Langton, W. B. Clark, A. W. Grabau, W. N. Rice, and the author. It is printed as pages 137–150 of this volume.

The last paper of the morning session was the following:

GEOLOGICAL BOOKKEEPING

BY JAMES F. KEMP

The subject was discussed by H. S. Williams, A. P. Coleman, and the author. The paper is published as pages 411–418 of this volume.

Following the discussion of Professor Kemp's paper the Society adjourned for the noon recess.

At 2.20 o'clock p m the Society reconvened, and the first paper read was

ROCK CLEAVAGE

BY C. K. LEITH

This paper is published as Bulletin number 239 of the U. S. Geological Survey.

The second paper was

ORIGIN OF THE CAVES OF THE ISLAND OF PUT-IN-BAY, LAKE ERIE

BY EDWARD H. KRAUS

[*Abstract*]

The rocks of the Lower Helderberg are locally very much disturbed. The largest of the four caves open to the public is Perry's. The ceiling of this cave shows the folding very clearly and also some interesting irregularities, in that all the strata do not extend entirely across the cave. This gives the ceiling an appearance similar, to some extent, to an inverted steps. The floor of the cave conforms to the unevenness of the ceiling, for where there is a depression in the former there is a corresponding projection downward in the latter and vice versa. This phenomenon is, no doubt, the result of folding and subsequent collapse. In all probability the folding was caused by the hydration of anhydrite, for large deposits of gypsum have been encountered in the sinking of wells in the immediate vicinity. Cores from these wells show a large amount of brecciation. Inasmuch as the increase in volume caused by the hydration of anhydrite may be as high as 60 per cent, and since there is a large supply of water present to bring about the solution of the gypsum thus formed—the level of the lake is reached at a depth of about 40 feet—we have given the probable causes for the folding, leaching, and subsequent collapse.

Remarks were made by A. C. Lane, G. K. Gilbert, E. H. Kraus, M. L. Fuller, H. P. Cushing, and the President. The paper is published in the American Geologist, volume xxxv, pages 167–171, March, 1905.

The third paper was

MOUNTAIN GROWTH AND MOUNTAIN STRUCTURE

BY BAILEY WILLIS

Remarks were made by A. C. Coleman, with reply by the author.

Announcement of details relating to the annual dinner and the evening session were made by the Secretary.

The President called S. F. Emmons to the chair, and the next paper was

OVERLAP RELATIONS ALONG THE ROCKY MOUNTAIN FRONT RANGE

BY N. H. DARTON

The following paper was presented by the same author:

ZUÑI SALT LAKE

BY N. H. DARTON

[*Abstract*]

Forty miles south of the Indian pueblo of Zuñi, there is, in the plain, a circular depression about a mile in diameter, containing a salt lake and two cinder cones. The depth of the depression is about 200 feet, and its walls are Cretaceous sandstone, capped on one side by a lava flow. All around the rim is a wide low ridge of water-laid volcanic ejecta. The history of this remarkable feature is not clear, but a hypothesis will be offered as to its origin.

The paper was illustrated with lantern slides. It is printed in the Journal of Geology, volume xiii, April–May, 1905, pages 185–193.

The last paper of the day was

EXPERIMENTAL INVESTIGATION OF THE COMPRESSIBILITY AND PLASTIC DEFORMATION OF CERTAIN ROCKS

BY FRANK D. ADAMS AND E. G. COKER

[*Abstract*]

The paper presents the results of an investigation into the cubic compressibility of rocks and certain phases of rock flow, carried out at McGill University by the aid of a grant from the Carnegie Institution. The apparatus employed and the methods adopted are first described. The cubic compression of rocks is then considered. Seventeen (17) typical rocks have been selected and their cubic compressibility determined. In these determinations an indirect method was employed which is believed to give as accurate results as any direct method known. The following are the rocks examined: Carrara marble, Vermont marble, Tennessee marble (pink), Belgian marble ("Noir Fin"), Montreal limestone (Trenton), Baveno granite, Westerly granite, Quincy granite (gray), Lily Lake granite, Peterhead granite, Stanstead granite, Montreal nepheline syenite, Mount Johnson essexite, New Glasgow gabbro, New Glasgow anorthosite, Sudbury diabase, Cleveland sandstone. From the standpoint of their compressibility as well as of their composition, these rocks fall into three main groups, as follows:

Granites	Value of D averages about	4,400,000
Marbles	" " " " "	6,300,000
Basic plutonics	" " " " "	8,800,000

The sandstone, being porous, has a much higher compressibility. D is the modulus of cubic compression, and is represented by a value the reciprocal of which is the decrease in volume of a cubic inch of the rock for a pressure of one pound per square inch. The question of the amount of pressure required to deform rocks was then investigated. This investigation was directed to obtain an answer to a problem stated by Mr G. K. Gilbert as follows: "It has been thought that great pressure breaks down the structure called solidity, and so reduces viscosity that very little differential stress is necessary to produce flow. It is thought that the strength of rocks is practically unaffected by pressure. It is certainly conceivable also that the strength of rocks is increased by pressure, so that the production of flow requires differential stress greater than the crushing stress as conditioned by the temperature."

The rocks investigated were Cockeysville (Maryland) dolomite, Carrara marble Belgian marble ("Noir Fin"), and Baveno granite. The investigation shows that when a rock is submitted to differential stress after the elastic limit has been exceeded and the texture of the rock has been broken down, owing to the internal, friction of the mass, the differential stress required to produce movement in the deformed rock is much greater than the pressure required to start deformation by breaking down the original texture] of the rock. Certain figures are presented in the case of each of the rocks and their mathematical significance described. It is shown that this work opens up a very extended field for investigation.

The results of a series of experiments on the deformation of rock-making minerals is then described.

The deformation of Carrara marble under much higher pressures than those employed in a former investigation on the flow of marble was then studied, the rock being inclosed in tubes of nickel steel, for which the authors are indebted to the Bethlehem Steel Company. Under the very high pressures employed a perfect plastic flow was developed in the marble at the ordinary temperature. Carrara marble was also deformed very quickly under a high pressure and a comparison made between the deformed marble and overstrained metals in respect of the influence of time and of heat in increasing the strength of the deformed rock. As in the case of steel, it was found to become stronger by simple lapse of time. The influence of rate of deformation upon the strength and character of the marble was also studied.

The work was then extended to the deformation of limestones containing various impurities, such as sand, clay, bituminous matter, etcetera, some of them being highly fossiliferous.

The paper concludes by presenting the results of the study of the deformation of series of dolomites that from the Beaver Dam quarries, Cockeysville, Maryland, being most thoroughly studied, and with a description of some preliminary experiments on the deformation of granite.

The paper was discussed by J. F. Kemp, C. K. Leith, and A. P. Coleman.

SESSION OF THURSDAY EVENING, DECEMBER 29

At 6.30 o'clock the annual dinner was served at the Hotel Walton, with ladies and other guests present.

At 8.30 o'clock the Society met in formal session in a parlor of the

Hotel Walton, and the President of the Society, John C. Branner, delivered an address entitled

STONE REEFS ON THE NORTHEAST COAST OF BRAZIL

The address is printed as pages 1–12 of this volume.

Following the presidential address a social reunion was held in the same room.

SESSION OF FRIDAY, DECEMBER 30.

The Society met at 10 o'clock a m, President Branner in the chair.

The Council report was taken from the table and adopted without debate.

AUDITING COMMITTEE'S REPORT

The Auditing Committee reported that all the accounts of the Treasurer had been found correct, and the report was adopted.

Announcements relating to the program and administrative details were made by the Secretary.

An invitation was read from the Directors of the Zoological Society of Philadelphia to visit the Zoological Garden, inclosing cards of admission.

The scientific program was declared in order, and the first three papers were presented by the same author, as follows:

PRESENT CONDITION OF MONT PELÉ *

BY EDMUND OTIS HOVEY

[*Abstract*]

The condition of Mont Pelé during the year 1904 was described as being one of continued activity, with occasional comparatively heavy outbursts. The form of the dome surmounting the volcano has suffered much change from time to time, several large needles having at times formed the profile, sometimes with and sometimes without a predominating needle on the site of the great spine of 1902 and 1903. During September the main mass of the dome rose, while the altitude of the extreme summit remained stationary through compensating losses from the top.

Early in January the remains of the obelisk, or spine, of the spring of 1903, which was destroyed in the summer and fall of that year, were reported to be rising again with reference to the other portions of the dome. In October, however, the dome lost about 100 meters of its altitude, which is 40 meters more than the gains of the preceding ten months. This loss was followed on October 10 by a loss of about 10 meters from the top of the terminal tooth of the dome.

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* December, 1904.

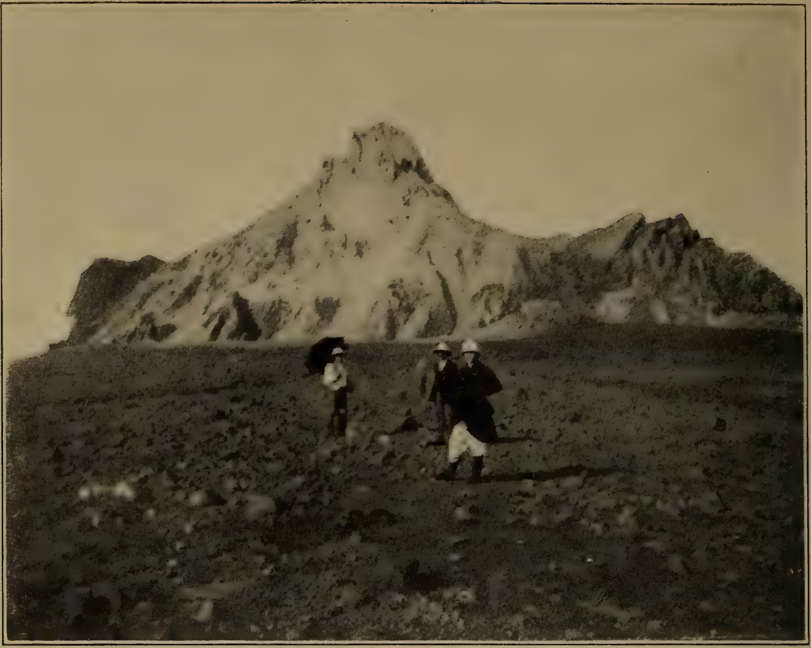

FIGURE 1.—SUMMIT OF MONT PELÉ

Looking southwest from the basin of the Lac des Palmistes. October 18, 1904. The central summit is the residue of the great spine of March, 1903. This view was taken from nearly the same spot as that published by the author in the American Journal of Science, October, 1903.

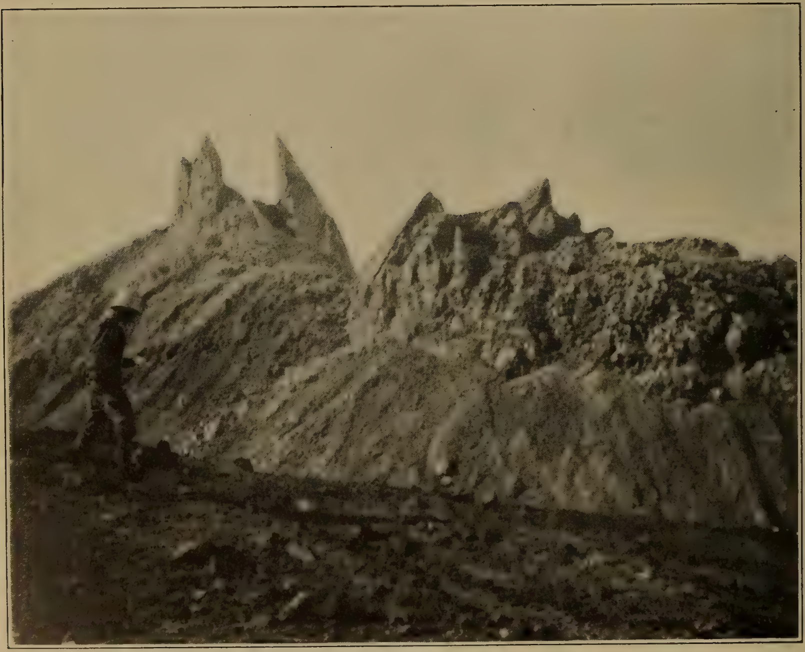

FIGURE 2.—SUMMIT OF MONT PELÉ

From the northern rim of the ancient crater. October 18, 1904. This view is at an angle of about 45 degrees from the preceding, and shows the serrate character of the summit of the new dome. Photographs by L. Guinoiseau.

SUMMIT OF MONT PELÉ

In November the great spine was observed to be slowly rising again, a movement which was checked in the latter part of the month. The official reports, as published in the "Journal Officiel de la Martinique," from which the data printed in this notice were obtained, are somewhat obscure, but it seems that there has been a net loss of about 80 meters during the year.

The valley between the new cone and the remains of the ancient crater, which was estimated to be about 200 feet deep in March, 1903, has been greatly reduced in depth by the debris thrown into t by the spasmodic partial demolition of the rising dome.

Frequently luminous points were observed in the dome at night, and the almost constant gentle discharge of steam was varied at irregular intervals by explosions of reddish or whitish dust-laden steam clouds. Some of these clouds descended into the upper valley of the Rivière Blanche, others toward Prêcheur, and a few expended their force toward the east, over the site of the Lac des Palmistes. On April 26 the ascending column of steam sometimes attained an elevation of 3,000 meters. An equal altitude was attained by the steam clouds in the latter part of September and again in November and December.

The author discussed briefly the origin of the dome and spine, referring to the three theories that have been advanced to account for it. He dismissed the idea that it had been formed through the piling up of plastic fragments,* by calling attention to

(1) The shape of the mass and its component parts as not being those of an exogenous cone;

(2) To the appearance of the whole, which was and is that of a relatively homogeneous though much rifted rock-mass;

(3) To the corrugated northeastern surface of the spine of 1902–1903, which preserved vertical striations probably due to friction against the wall of the conduit;

(4) To the fact that the scores of major and minor eruptions which had been observed had uniformly thrown their ejecta beyond the rim of the great crater surrounding the dome or down the debris slopes into the valleys of the Blanche, Claire, La Mare, and Prêcheur rivers.

The author considers untenable the second theory also, which is that the dome and spine are the elevated plug of ancient lava supposed to have closed the conduit before the activity of 1902 began.† The volcano of mont Pelé is a composite affair, made up of beds of solid lava and fragmental debris (tuff), the latter by far predominating.

It is entirely probable that some of the previous eruptions have been of the character of the present outbreak and that some of the massive lava beds now in evidence originated as massive solid exudations.

The causes of the inception and cessation of volcanic activity are not sufficiently well known to assert that a plug of solid lava necessarily fills the conduit of a volcano at the quiescence of a vent.

The total elevation of dome and spine, had no losses occurred, would probably have amounted to not less than 6,000 feet above the bottom of the old crater. This, according to the "elevated plug" theory, would predicate the presence of a stopper of cold or, at any rate, solid lava at least 6,000 feet in vertical measurement. The probable cross-section of the conduit or system of conduits of eruption was about 1,500 feet in diameter. Such a vast mass of rigid lava certainly would offer greater resistance to ascending eruptive forces than would the surrounding fragmental beds, and it would not be lifted bodily into the air. A new vent would more probably be opened beside the old plug or the rising heat would melt its way through the plug.

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* T. A. Jaggar, Jr.: The initial stages of the spine on Pelée. Am. Jour. Sci., iv, xvii, 39. Jan. 1904.

† A Heilprin: The tower of Pelée. 1904. J. B. Lippincott Co.

A violent eruption like that of Mont Pelé on May 8, 1902, would certainly have cleared the conduit of the volcano or at any rate have given a practically free course to the rising eruptive material. The clearing of the conduit had been going on gradually, but with increasing violence, for some weeks before the catastrophic explosion occurred which overwhelmed Saint Pierre.

If the ancient conduit were occupied with congealed lava prior to 1902, the revived volcanic agents found their way through the plug or ejected it in fragments into the air before the massive dome and spine began to form. Such action might or might not leave a tubular ring of solid lava around the new conduit. If such a tube were left between the conduit and the main tuff beds of the mountain, it hardly seems possible that the eruptive forces could get under it or between the tube and the matrix in such manner as to lift the shell bodily into the air. If no tube of solid lava were left, there would be no shell of ancient lava to be elevated as even the remnants of a plug. The positive arguments, however, in favor of the third theory are more convincing than the negative arguments which have been advanced against the second hypothesis.

The third theory is that the dome and spine consisted of lava which solidified and became rigid as it was extruded or else in the upper part of the conduit, at least to such an extent that no flow of lava resulted. This is the theory which the author has advocated* and which accords with that advanced by Professor Lacroix,† who first recognized the fact that the new cone of eruption was mainly massive and not fragmental in character. More recently the theory has been elaborately and ably defended by Israel C. Russell.‡

The lava of Pelé is andesitic in type and therefore rather difficult to fuse. The result is a viscous stream at the ordinary temperature and under the usual conditions of eruptions. In some of the preceding eruptions of Pelé streams of molten lava have issued from the vents and flowed short distances; in most, however, there has been sufficient excess of water vapor present to produce entirely explosive eruptions. The presence of expanding gas and vapor lowers the temperature of the containing fluid, the effect increasing with increase in the proportionate amount of gas and vapor present. The sudden diminution of pressure at the vent of the volcano produced corresponding expansion of the occluded gases and rapid lowering of temperature, with resulting greater or less solidification.§ At Pelé, after the outburst of May 8, 1902, the balance between forces was so nicely adjusted that the lava welling up out of the conduit congealed as it rose and formed the famous dome and spine instead of flowing down the mountain in a stream.

The lava near the walls of the conduit would naturally be cooler and therefore more viscous than that near the center of the rising column. The result would be the freer rise of gases and vapor through the center than through the sides of the

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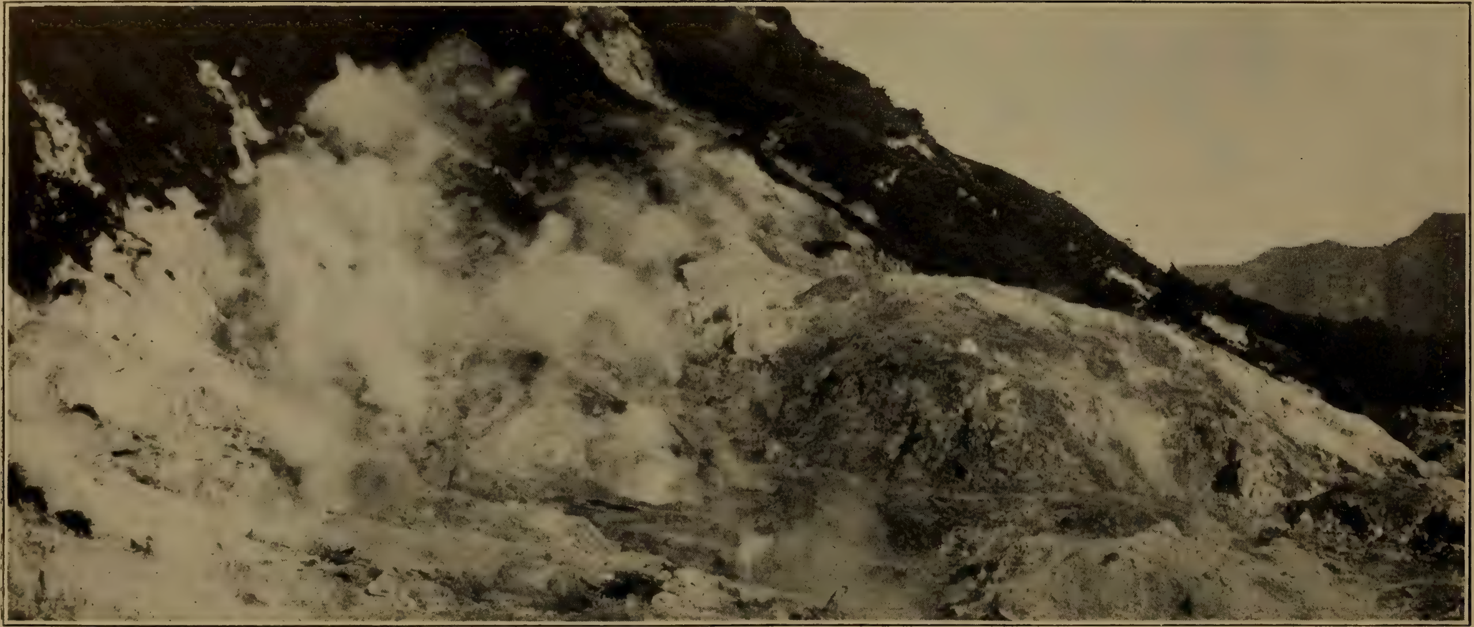
* C. R. IX Congr. Geol. int. de Vienne, 1903, pp. 724, 734.

† Comptes Rendus, 27 Oct., 1902.

‡ Science, n. s., vol. xxi, p. 924.

§ See A. C. Lane, in Science, n. s., vol 18, p. 760, and G. K. Gilbert, in Science, n. s., vol. 19, p. 927.



SOUFRIÈRE OF SAINT LUCIA

Looking northwest. March 17, 1903. Principal boiling springs and fumaroles are to the left. To the right is the mound, 30 feet high, consisting of solidified mud (decomposed rock) impregnated with sulphur, alum, ferrous sulphide, etcetera. Part of the mass seems to be made up of land-slide material from the side of the mountain. Photograph for the American Museum of Natural History by E. O. Hovey.

mass, whether there were a constantly open vent or vents there or not. The activity was not central within the old crater, but was most intense in the northwestern quarter. This eccentricity allowed the lava of the southern portion of the conduit to exude rather continuously and solidify as a very steep-sided cone which was disturbed perhaps only during the heavier eruptions. The eccentricity of the maximum activity seems also to account for the northern portion of the dome rising faster than the southern. The relief of pressure at the orifice of the general conduit permitted expansion of the occluded gases and vapor, which increased the cross-section of the dome with reference to the conduit and maintained it in position, even when there was little pressure from below or rise of material. In the extreme northern part of the crater there is an area of new rock which, like the southern portion, has not risen as rapidly or as much as the subcentral part bearing the spine. The spine-bearing portion of the dome seems to have been comparatively independent of the other two rock portions of the dome and probably was separated from them by actual or potential fracture zones.

SOUFRIÈRE OF SAINT LUCIA *

BY EDMUND OTIS HOVEY

[*Abstract*]

The island of Saint Lucia is entirely volcanic in origin. The rocks and tuffs of the island have suffered extreme subaereal alteration; erosion is in an advanced stage, and volcanic eruptions seem to have ceased on Saint Lucia long before they did on any other of the inner line of the Caribbees. No semblance of a volcanic cone or crater has been reported from any part of the island, but the northern end of the island might repay search for recognizable remains of strato-volcanoes, as indeed has been suggested by Sapper. Warm springs are known to occur in several places on the island, but the only important locality is one called the Soufrière, which lies about a mile east of the northern of the two remarkable pinnacles of volcanic rock, which rise precipitously from the sea about 13 miles south of Castries and are known as the Gros and the Petit Piton. This fumarole area covers 2 or 3 acres of the Ventine estate near the head of one branch of the valley which discharges at the little town of Soufrière on the west coast a mile or more north of the Petit Piton.

At the time of the author's visit, March 16–18, 1903, there were within the area eight distinct boiling springs, one vigorous blow hole, which was driving out with much force and noise the water flowing into it from a little stream, many less vigorous vents, and numberless quiet fumaroles. The water was thoroughly boiling in the large springs and was scalding hot in the smaller ones. During the rainy season there is much more water in the springs than there was at the time of the author's visit, the temperature of the springs is lower, and the activity less violent. The pools vary in size up to 30 feet in diameter.

The vapor rising from these vents is steam charged with varying quantities of hydrogen sulphide. Crystalline sulphur is forming around most of the fumaroles and in the cavities of the porous deposits from the springs which are permeated by the volcanic gases. Ferrous sulphide blackens the mud of many of the springs, particularly the quieter ones. Alum forms in places from the discharges and min-

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* Based upon field observations made for the American Museum of Natural History.

gles with the sulphur. Kaolin results from the decomposition of the feldspars of the original rocks.

The sulphur springs area lies on the northeast flank of the Soufrière mountain, and seems not to be the remains of or connected in any way with an ancient crater. It is not always easy, or perhaps even probable, to determine the exact position of beds which are so deeply decomposed and so heavily covered with vegetation as these of Saint Lucia, but the convex character of the ridge on which the sulphur springs area is located and the general relations of the mountains to one another seem to preclude the idea of the existence of a crater at this point. Some effort has been made to mine the sulphur deposited here, but the enterprise has not been a commercial success.

The paper was illustrated with lantern slides.

BOILING LAKE OF DOMINICA[*]

BY EDMUND OTIS HOVEY

[*Abstract*]

The island of Dominica is entirely volcanic in origin, but high-level marine beaches and benches, coral beds, and river terraces indicate comparatively recent elevation amounting to not less than 500 feet. Dominica is one of the largest and highest of the Lesser Antilles. The altitude of the land mass produces copious precipitation, and the surface consequently is well dissected. The rivers for the most part are still deepening their V-shaped channels, and only the larger streams, like the Roseau, the Layou, and some others, have flood-plains. Marine erosion has advanced more rapidly than stream erosion and bluffs form the major portion of the coast.

Many warm and hot springs and fumaroles occur in different parts of the island, and residents report the existence of volcanic craters in Morne Diablotin, the culminating point of the island (4,747 feet), and elsewhere in the mountains. The best known and most important center of volcanic activity is the Grande Soufrière, about 6 miles east-northeast of the town of Roseau. Here is situated the famous Boiling lake of Dominica. The Grande Soufrière was in feeble eruption for a brief period in 1880, ashes being thrown as far as Roseau.

The whole fumarole area of the Grande Soufrière is nearly a mile in longest diameter, from southwest to northeast, and occupies a vast amphitheatrical depression in the northeast flank of Watt mountain. The amphitheater is breached to the base toward the southeast, and resembles in form the present craters of Montserrat and Nevis and that of Mont Pelé before the eruptions of 1902 began. Within the great crater-like depression there are many hot springs and steam vents, most of which arrange themselves into four groups. The principal of these springs or groups is the Boiling lake, lying in the extreme northeastern portion of the great amphitheater.

The Boiling lake is a circular pool of boiling water 50 or 60 yards across, in the bottom of a pot-like basin, which may be 100 yards in diameter at top. The surface of the lake is about 560 meters (1,837 feet) above the sea by uncorrected aneroid measurement. Two beaches, about 2 and 5 feet above the water at the

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[*] Based upon field observations made for the American Museum of National History.

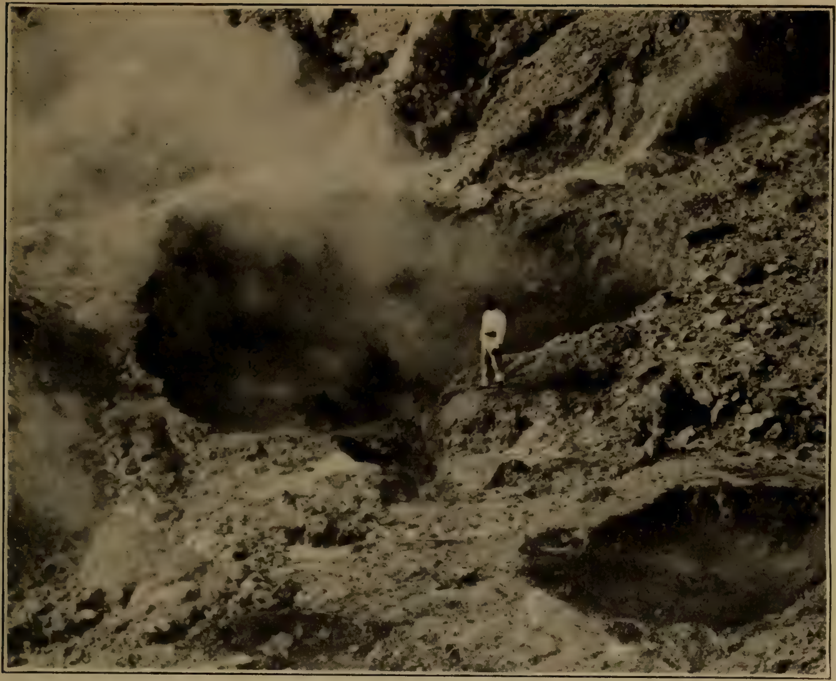

FIGURE 1.—GRANDE SOUFRIÈRE OF DOMINICA

Near view of one of the largest of the boiling springs. March 17, 1903. This is a true spring the bowl of which is about 30 feet in diameter. No surface water was flowing into the bowl at the time of the author's visit, and there was a streamlet flowing out of it.

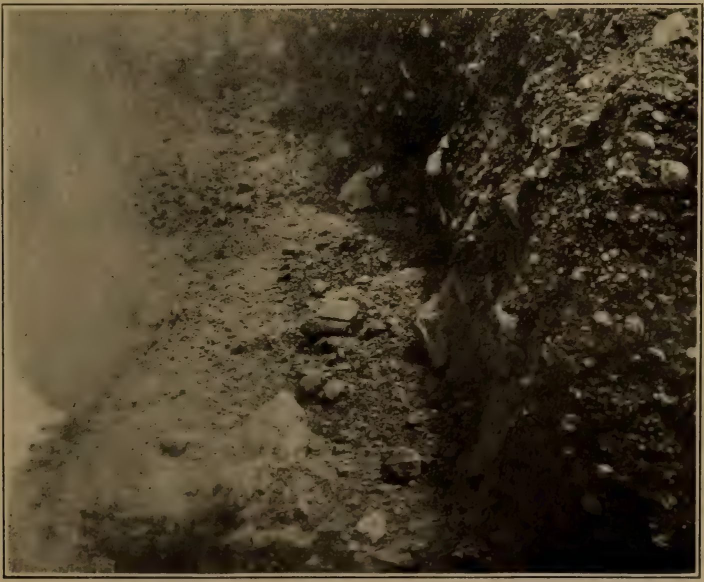

FIGURE 2.—BOILING LAKE OF DOMINICA

Southern portion of basin beside outlet. Shows indistinct terraces and the composition of the wall. Photographs for the American Museum of Natural History by E. O. Hovey

SOUFRIÈRE AND BOILING LAKE OF DOMINICA

time of the author's visit (April 5, 1903), show that the lake stands at higher levels during rainy seasons, with corresponding increase in diameter. Two small streams of cool water flow into the basin from the north-northwest, while a single stream discharges the overflow of the pool toward the south-southeast.

There are two centers of ebullition, one of gentle action in the northeastern quarter of the pool and one of great vigor in the western third. Over the latter the water rises in a dome about 2 feet higher than the general level of the lake, and occasional jets throw water 5 or 6 feet into the air. The quantity of water ordinarily rising through the two conduits indicated by the centers of ebullition seems to be rather small, judging from a comparison between volumes of the inflowing and outflowing streams. It probably varies with the seasons.

The gas rising from the Boiling lake is mostly water vapor (steam), which must have a temperature of fully 100 degrees Centigrade at the vents, since the temperature of the brook leaving the pool is 87 degrees to 88 degrees Centigrade, as determined by Sapper. A strong odor of sulphur gas (seemingly H_2S) pervades the steam. The water of the lake is bluish milky white fram the particles of precipitated sulphur which it carries in suspension. Carbon dioxide also seems to be present in the discharge from the vents, to judge from the death by asphyxiation of the Englishman, Mr Clive, and his porter on the border of the pool in December, 1901. Sometimes, according to Matson Rolle, the guide, when the lake is very full, the strong boiling ceases and bubbles of gas and steam rise copiously from all parts of the lake. On days when such conditions prevail the lake is particularly dangerous to approach.

The basin has been formed by the action of the fumaroles and spring water, in conjunction with the surface water, undermining and removing the slide rock and debris from the mountain. Mud is thrown out occasionally from the lake, but the walls of the basin seem to have been built up by ejected materials. Matson Rolle and other residents of the colony state that during exceptionally dry seasons the streams disappear and the basin is empty, except for periodic inflows through the fumarolic vents in its bottom. The basin, therefore, is shallow, a fact that was indicated also by the shape of that part of the bottom visible at the time of the author's visit. The walls of the basin rise about 15 feet above the water at the outlet, about 60 feet on the west side of the pool, and somewhat higher on the east side. They are vertical or nearly vertical, but the borders of the pool can be easily attained along either the inflowing or outflowing stream.

The intermittent rising and falling of water in the conduits during times when the basin is dry, observed by Mr Bell, administrator of the colony, and reported by Sapper, points toward geyser action, but the fountain-like discharge of typical geysers is absent.

The paper was illustrated by means of lantern slides.

The three papers by Doctor Hovey were discussed as one by Angelo Heilprin, I. C. Russell, and the author.

The fourth paper was presented in abstract by the Secretary, the author being absent, as follows:

NITROGEN GAS WELL AT DEXTER, KANSAS

BY ERASMUS HAWORTH

[*Abstract*]

The well, 400 feet deep, is in Cowley county, southern Kansas, the top being in Permian strata and the gas-bearing sandstone lying near the division between the Lower Permian and the Upper Coal Measures. The static pressure of the gas is 120 pounds and the flowage capacity is 5,000,000 cubic feet daily. An amount of gas equal at atmospheric pressure to 125,000,000 cubic feet has been allowed to flow from the well. The following table of its composition was made after the gas had been allowed to freely flow for eleven days through an 8¼-inch pipe and for three days more through a 3-inch pipe.

Carbon dioxide	0.00
Carbon monoxide	0.00
Oxygen	0.20
Hydrogen	0.80
Methane (CH_4)	15.02
Nitrogen	71.89
Inert residue	12.09
Total	100.00

The full paper is published in Science, volume xxi, February 3, 1905, pages 191–193.

The fifth paper was

PIEDMONT DISTRICT OF PENNSYLVANIA

BY F. BASCOM

The paper was discussed by B. K. Emerson, Persifor Frazer, C. D. Walcott, and the author. It is printed as pages 289–328 of this volume.

The sixth paper was then read, as follows:

CORRELATION OF MARYLAND AND PENNSYLVANIA PIEDMONT FORMATIONS

BY EDWARD B. MATHEWS

The paper is printed as pages 329–346 of this volume.

The President called Vice-President H. S. Williams to the chair.

The seventh and last paper of the morning session was read:

COCKEYSVILLE MARBLE

BY EDWARD B. MATHEWS AND W. J. MILLER

This paper is printed as pages 347–366 of this volume.

The Society adjourned for the noon recess. On reassembling at 2.10 o'clock, Vice-President H. S. Williams in the chair, it was announced that the papers in petrography would be presented in a separate section, to meet in room 104 of the same building. The general program was continued in room 116 and the first paper was

EFFECT OF CLIFF EROSION ON FORM OF CONTACT SURFACES

BY N. M. FENNEMAN

The paper is printed as pages 205–214 of this volume.

The second paper was

DRAINAGE FEATURES OF CENTRAL NEW YORK

BY RALPH S. TARR

Remarks on the subject of the paper were made by G. K. Gilbert, W. M. Davis, and the author. The paper is printed as pages 229–242 of this volume.

The third paper was

HANGING VALLEYS

BY ISRAEL C. RUSSELL

This paper is printed as pages 75–90 of this volume.

The fourth and last paper of the day was the following:

ICE EROSION THEORY A FALLACY

BY H. L. FAIRCHILD

The paper was discussed by J. W. Spencer, A. C. Lane, A. P. Coleman, I. C. Russell, G. K. Gilbert, W. M. Davis, and the author. The paper is printed as pages 13–74 of this volume.

The Society adjourned. No evening session was held.

SECTION OF PETROGRAPHY

During Friday afternoon, while the papers described above were presented in the general session the papers classified on the printed program as petrographic were presented in room 104. The temporary section was called to order by J. P. Iddings, and by *viva voce* vote B. K. Emerson was made Chairman and E. O. Hovey Secretary.

The first paper presented was

GARNET CONTACT ZONES AND ASSOCIATED COPPER ORES AT SAN JOSÉ, TAMAULIPAS, MEXICO

BY J. F. KEMP

The paper was discussed by J. P. Iddings, H. S. Washington, Whitman Cross, and A. C. Lane. It will be published in the transactions of the American Institute of Mining Engineers.

The second paper was

OCCURRENCE AND DISTRIBUTION OF CELESTITE-BEARING ROCKS

BY EDWARD H. KRAUS

[*Abstract*]

A study of the rocks—shales and dolomitic limestones—of the upper portion of the Salina epoch in central New York shows that celestite occurs quite widely disseminated throughout them (1) in the form of well developed crystals and (2) in small circular spots. The celestite was no doubt deposited simultaneously with the rock material. The rocks on the island of Put-in-Bay, lake Erie, and in southern Michigan, especially those at the Maybee quarry, Monroe county, show a similar occurrence of celestite. When celestite-bearing rocks are leached by the action of circulating water the celestite passes quite readily into solution, and the rock then assumes a porous character; in this manner the so-called "vermicular limestones" of New York, and also the "gashed" and "acicular" dolomites of Michigan, may be explained. Such celestite-bearing rocks are also the source of the large deposits of celestite which are so abundant on the islands of lake Erie—especially Put-in-Bay—and at the Maybee quarry, Monroe county, Michigan.

The paper was discussed by A. C. Lane, A. P. Coleman, E. H. Kraus, G. P. Merrill, and the Chairman. It is published in full in American Journal of Science, volume xix, pages 286–293, April, 1905.

The third paper was

LIMESTONES OF CENTRAL AND SOUTHERN CALIFORNIA

BY T. C. HOPKINS

Remarks were made by J. S. Diller.

The fourth paper was

ORIGIN OF VEINS IN ASBESTIFORM SERPENTINE

BY GEORGE P. MERRILL

The paper was discussed by A. P. Coleman, J. P. Iddings, F. D. Adams, J. F. Kemp, and the Chairman. It is printed as pages 131–136 of this volume.

The fifth paper was

SOME CRYSTALLINE ROCKS OF SAN GABRIEL MOUNTAINS, CALIFORNIA

BY RALPH ARNOLD AND A. M. STRONG

The paper was discussed by E. H. Kraus and H. S. Washington. It is printed as pages 183–204 of this volume.

The sixth paper was

SUGGESTION AS TO THE ORIGIN OF RIEBECKITE ROCKS

BY G. M. MURGOCI [*]

Riebeckite rocks have been found by the author in the Dobrogea, and have been studied *in situ* in relation to the rocks around them, especially the granites, diorites, porphyries, and diabases, and in the laboratory, where they have been compared with riebeckite rocks from Scotland, Wales, Rhenish Prussia, and Quincy, Massachusetts. In the Dobrogea they form large patches and undulating zones, so called "Schlieren," mixed at random with similar rocks without riebeckite, but very acid and very poor in black constituents. In all riebeckite rocks a spongy, so to speak, a pseudopoikilitic texture, has, as is well known, been observed.

Riebeckite has been formed continually during the whole time of the consolidation of the rock. It is sometimes found as microlites included in other constituents, and as patches cementing feldspars, and even quartz; also in microlitic cavities or in cracks of minerals and rocks filled by pegmatitic masses. Zircon (Lacroix found up to T. 5 per cent), which accompanies riebeckite, has been formed also during the entire period of consolidation of the rock. Some riebeckite undergoes reactions immediately after its formation, such as yielding pseudomorphs of zircon and quartz after it, chloritization, variation in its composition at the surface or in patches, etcetera.

The study of the inclusions of riebeckite granite, which are found in great numbers in the granite of Dobrogea, throws light on many questions. There are homogenetic, pneumatogenetic, and polygenetic inclusions, the first-named being separations of riebeckite, with spongy quartz, zircon, titanite, hematite, pyrochlore, etcetera, as large crystals. The pneumatogenetic inclusions are hollow, with a great deal of fluorspar, zircon, titanite, galena, pyrites, pyrrhotite, mispickel, hematite, etcetera. In the polygenetic inclusions large crystals of orthoclase and acid plagioclase, pyroxenes (augite, ægerite), amphibole, hornblende (common hornblende, arfvedsonite), black mica, chlorite, and uralite.

The same inclusions have been observed by the author in the granite of Quincy, Massachusetts.

The magma which has given rise to the riebeckite rocks develops from a reservoir by a process of magmatic differentiation, caused by the abundance of mineralizers, which also keep it acid. On account of the impermeability of the layers of argillaceous shales between which it has been introduced, the mineralizers are not lost; they continue to act on the magma and to combine with it.

The presence of fluorspar, zircon, and sulphides as constituents of riebeckite rocks, the existence of pneumatogenetic and polygenetic inclusions, and the contact layers with the same minerals, all speak for this view of the case. New relays of fluid masses would cause streams and vortices in the consolidating magma, and in this way the "Schlieren," with their varying structure, would arise; also the crushing of feldspars and riebeckite cystals, which are cemented by the new substance. The magma was extremely acid, fairly rich in aluminum, sodium, and potassium, but the great quantities of titanium and fluorine have been brought by mineralizers, which were not rich in H_2O, S, etcetera, but were characterized by abundance of zirconium. As Lacroix remarks, zirconium has played a part in riebeckite granites similar to that played by tin in cassiterite granites.

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[*] Introduced by J. F. Kemp and E. O. Hovey.

To conclude, one may say that riebeckite rocks (and particularly those of the granite-rhyolite series) have become solid under the following circumstances: A very acid magma under high pressure and kept in motion by fresh arrivals of mineralizers, which are characterized by zirconium, fluorine, and titanium, and which have been gradually absorbed and utilized for the formation of the constituents of the rock, especially riebeckite and zircon. There was absence of past volcanic activity, and the contact phenomena were reduced but characteristic. One could suppose that this suggestion would come under the head of the phenomena connoted by piezocrystallization of Weinschenk.

The paper of Doctor Murgoci was discussed by J. F. Kemp, H. S. Washington, and the Chairman.

SESSION OF SATURDAY, DECEMBER 31

The Society met at 9.30 o'clock a m, President Branner in the chair.

The Secretary announced that the Council had decided to hold the next annual meeting in Ottawa, Canada.

The presentation of papers was declared in order, and the first paper read was

GEOLOGY OF GREAT SLAVE LAKE

BY ROBERT BELL

The second paper was

NEW YORK DRUMLINS

BY H. L. FAIRCHILD

[*Abstract*]

A brief description of the drumlins of New York with reference to their distribution; altitudes or direction of major axes; relation to the larger topography; relation to the underlying rocks; composition; structure; form; size; origin.

The paper was discussed by R. S. Tarr, A. C. Lane, and B. K. Emerson. It will be published by the New York State Museum.

The third paper was, in the absence of the author and by vote of the Society, read by I. C. Russell, entitled

DRUMLINS IN THE GRAND TRAVERSE REGION OF MICHIGAN

BY FRANK LEVERETT

[*Abstract*]

The paper discussed the distribution, form, structure, and modes of development of the drumlins of the northwestern part of the southern peninsula of Michigan. Particular attention is given to modes of development, since more than one mode appears to have been operative. Some drumlins have been sculptured from earlier deposits at the last ice advance and some built up during that advance from material contained in the ice. Attention was called incidentally to heavy deposits of nearly pebbleless laminated clay, apparently laid down in interglacial lakes, for this clay has been molded to some extent into drumlin forms by a subsequent ice invasion. Large valleys excavated in this interglacial clay were briefly discussed and shown to antedate the production of the drumlins, the latter being in some cases built on the valley bottom.

In view of the fact that a large number of papers were yet to be presented and the time limited, it was voted that for the remainder of the morning a temporary Section of Stratigraphy should be organized in another room of the building, before which certain of the papers should be read.

The fourth paper in the general session was

DRUMLIN AREAS IN NORTHERN MICHIGAN

BY ISRAEL C. RUSSELL

[*Abstract*]

There are at least two regions in the northern peninsula of Michigan in which drumlins form the most conspicuous features of the topography. One of these areas includes Les Cheneaux islands and a part of the adjacent mainland, on the north shore of lake Huron, and the other area is situated principally in Menominee county, to the west of Green Bay.

Les Cheneaux islands area embraces about 70 square miles; the numerous drumlins within it are of the elongate, ridge-like type, are in general about 40 feet high, and trend northwest and southeast. The direction of ice movement to which the drumlins are due, as recorded by striæ, etcetera, on rock surfaces, was from the northwest toward the southeast. Many of the drumlins are partially submerged in the water of lake Huron and form Les Cheneaux islands and the capes on the border of the adjacent mainland; the conspicuous parallelism of the longer axes of the islands and of the neighboring capes is due to this cause. The drumlins are for the most part below the horizon of the Nipissing beach, and have been washed by lake waters so as to remove the greater part of the fine material formerly present on their surfaces, and concentrate the stones and boulders.

The Monominee area occupies at least 150 square miles, and contains many hundred and probably several thousand drumlins. The drumlins are mostly of the ridge-like type, are usually about 40 feet high, and their longer axes trend northeast and southwest. The till of which they are composed is reddish, sandy, without lamination, and contains many flat slabs of limestone which are without orderly arrangement. Boulders of native copper and of specular iron ore found in the till indicate that it was deposited by a glacier moving from the northwest toward the southeast. Striæ, etcetera, on rock surfaces in the midst of the drumlins record an ice movement from the northeast toward the southwest. The longer axes of the drumlins are not strictly parallel, but vary in trend from north 32 degrees east to north 55 degrees east. The rock on which the drumlins rest is Trenton limestone and has a conspicuously even surface; no knobs or crags are present, such as might serve as nuclei for till accumulation. The larger drumlins rise to a uniform height, and if the valleys and channels between them were filled a nearly horizontal plain would be produced. The depressions separating the drumlins are in many instances smooth-surfaced, concave troughs, and in one example there is a well defined trench of this character, about 12 feet deep and from 20 to 30 feet wide, about the northeast end of a small drumlin and extending along its sides. The surfaces of the drumlins to a depth of some 12 to 18 inches are composed of exceedingly fine, dust-like, loamy sand, which contains loose stones and boulders.

The drumlins are for the most part smooth-surfaced, half cigar-shaped hills of the normal type, but in a few instances instructive irregularities are present. Among these are a flattening of a portion of the normally elliptical ground plan, as if a marginal portion of a well shaped drumlin had been removed by erosion, leaving an abnormally steep slope; deep transverse trenches at right angles to their longer axes; straight or curved trenches extending from their summits down their sides; irregular pits in their normally smooth surfaces; and in one instance, a terrace-like shelf with a convex longitudinal profile, parallel with the crest-line of the drumlin on the side of which it occurs.

In the valleys between the drumlins there are several eskers, which as a rule are in a general way parallel with their longer axes, but in a few instances cross their trend nearly at right angles. In one example an esker extends each way from a transverse trench in a drumlin, and in a few instances eskers occur on the tops of drumlins.

From the evidence just summarized the conclusion is drawn that the drumlins of the Menominee area were produced by ice erosion from a previously deposited till sheet. This explanation is essentially in harmony with the theory of the origin of drumlins advanced several years since by Professor Shaler.

Attention was invited to the importance of ice erosion in shaping the topography of glacial deposits in other regions.

Lantern views in illustration of the papers on drumlins were then shown and the papers discussed together. Remarks were made by W. M. Davis, R. S. Tarr, G. C. Martin, and B. K. Emerson.

The fifth paper was

MORAINES OF THE SENECA AND CAYUGA LAKE VALLEYS

BY RALPH S. TARR

Remarks on the subject of the paper were made by W. M. Davis. The paper is printed as pages 215–228 of this volume.

The sixth paper was

GLACIAL PROBLEMS IN CENTRAL NEW YORK

BY H. L. FAIRCHILD

The Society adjourned for the noon recess. At 2 o'clock the Society reconvened and resumed the reading of papers.

The first paper was

AGE OF THE MORRISON FORMATION

BY N. H. DARTON

Remarks were made by T. W. Stanton.

The second paper was

CLASSIFICATION OF THE UPPER CRETACEOUS FORMATIONS OF NEW JERSEY

BY STUART WELLER

[*Abstract*]

Three classifications of the upper Cretaceous formations of New Jersey have been published in the reports of the Geological Survey of New Jersey—1, Cook's, 1868; 2, Clark's, 1892–1897; 3, Knapp and Kummel's, 1898–1904. Cook based his classification upon the lithologic characters of the beds; fully differentiated the beds of the "marl" series. Clark's classification was based in part upon paleontologic data. He distinguished four major divisions, namely, Matawan, Monmouth, Rancocas, and Manasquan. Knapp and Kummel have differentiated the old "clay-marl" series of Cook into five formations, namely, Merchantville, Woodbury, Columbus, Marshalltown, and Wenonah, based upon lithologic characters alone.

The paleontologic studies of the writer not only add very largely to the previous data regarding the faunas of these beds, but also show (1) that the five "clay-marl" formations of Knapp and Kummel are as sharply differentiated by their fossil contents as by their lithologic characters, and (2) that the "yellow sand" of Cook, which was finally referred to the Miocene by Clark, is of Cretaceous age, being an arenaceous facies of the Vincentown lime-sand formation.

Remarks were made by H. S. Williams and H. B. Kummel.

The third paper was by the same author, entitled

FAUNA OF THE CLIFFWOOD CLAYS

BY STUART WELLER

[*Abstract*]

The flora of the Cliffwood clays on the south shore of Raritan bay, New Jersey, has been studied in detail by Hollick and Berry, but no careful study of the fauna of these beds had previously been attempted. An investigation of this fauna by the author shows its close ralationship to the faunas of the "clay-marl" formations above, but at the same time shows that the Cliffwood fauna possesses an individual character of its own. The geographic distribution of the beds containing the fauna is limited to a small area betweed Cliffwood point and the head of Cheesquake creek, while the superjacent Merchantville clay, with its uniform fauna, extends entirely across the state of New Jersey. The basal line of the Merchantville clays can be traced as a natural geologic horizon across New Jersey, separating the heterogeneous, usually non-marine Raritan beds beneath from the remarkably constant marine beds of the "clay-marl" formations above. The marine Cliffwood clays represent a limited transgression of the marine conditions from the Atlantic basin into the area where non-marine sedimentation had been in progress during the greater portion of Raritan time. These Cliffwood clays are the most notable example of such marine sediments in the Raritan, but not the only example, since marine fossils have also been found toward the base of the Raritan near Sayresville. In mapping the Cliffwood clays they should be included in the Raritan rather than with the superjacent beds.

The paper was discussed by H. B. Kummel, T. W. Stanton, H. S. Williams, and Arthur Hollick. The full paper will be printed in the annual reports of the Geological Survey of New Jersey.

The fourth paper was

MESOZOIC SECTION OF COOK INLET AND THE ALASKA PENINSULA

BY T. W. STANTON AND G. C. MARTIN

Remarks were made by H. M. Ami and the author. The paper is printed as pages 391–410 of this volume.

The fifth and last paper presented in full was the following:

TERTIARY LIGNITE OF BRANDON, VERMONT, AND ITS FOSSILS

BY GEORGE H. PERKINS

The paper is printed as pages 499–516 of this volume.

The temporary section of stratigraphy organized with H. S. Williams as Chairman and J. F. Kemp as Secretary. The following six papers were read :

PRE-CAMBRIAN ROCKS IN THE VICINITY OF LAKE TEMISKAMING, ONTARIO

BY WILLET G. MILLER

[*Abstract*]

Two areas of pre-Cambrian rocks in northwestern Ontario, those of the "Original Huronian" area on lake Huron and of the Rainy River district, have been somewhat closely studied, and the reports on them have become almost classic. Lake Temiskaming, which is on the eastern boundary of the province, lies over 200 miles east of the former area. Although numerous descriptions have been published of the crystalline rocks of the region lying between these two localities, little success has been achieved in subdividing and classifying them. A. E. Barlow's work of a year ago showed that there are two series in the vicinity of lake Temagami, an older complex igneous group and a younger fragmental group, together with later intrusions.

During a part of the past summer the writer has been engaged in mapping an area of about 15 miles square which lies at the northwest corner of lake Temiskaming, 25 miles north of Temagami. In this area he has discovered two unconformable fragmental series among the pre-Cambrian rocks. (1) The oldest group of rocks here is similar to the older of the two groups at Temagami. It consists of a complex assemblage of igneous rocks which may be broadly divided into three varieties, although others are present. The oldest of the varieties can now be called a greenstone. It is cut by quartz-porphyry. The two have been subjected to folding and are cut by granite. (2) After the granite eruption, erosion has taken place, giving rise to conglomerate and finer-grained, slate-like varieties. (3) There has been a second period of erosion, and deposited on the surfaces of the two older series there is a group or series of arkose and quartzite. (4) Each of these three series or groups is cut by diabases and gabbros of pre-Paleozoic age.

The oldest of these series of lake Temiskaming, the greenstone and quartz-porphyry with intruded granite, may, for the present at least, be correlated with the Thessalon greenstone, with associated granite, of the "Original Huronian," and with a part of the Keewatin of the Rainy River district; while the second series, that of the conglomerates and slate-like rocks, corresponds, in this area, to the conglomerate of the Lower Huronian of lake Huron. The arkose series of Temiskaming, which is unconformable to the conglomerate and slate, may here be considered to represent Logan's Upper Huronian of lake Huron. More detailed work may, however, show that there are still other unconformities in the Temiskaming area.

The second group or series, the conglomerate and slate, is of economic interest on account of the occurrence in it of ore deposits which, so far as is known, are unique on this continent. The ores are found in fissures, which, in dip, approach the vertical, cutting through the usually slightly inclined conglomerates and slates. Ore is being shipped from four properties. The chief ores are native silver, smaltite, and niccolite. Associated with these are native bismuth, erythrite, annabergite, chloanthite, cobaltite, mispickel, millerite, argentite, dyscrasite, pyrargyrite,

stephanite, tetrahedrite, graphite, and other minerals. It will be noted that this association of minerals is similar to that of deposits which have long been worked in Germany.

Remarks were made by B. K. Emerson.

RELATIVE AGES OF THE ONEIDA AND SHAWANGUNK CONGLOMERATES

BY A. W. GRABAU

[*Abstract*]

The Oneida and Shawangunk conglomerates represent different portions of a basal conglomerate in the transgressing Siluric sea. The Oneida portion is of mid-Medina age, the Shawangunk portion of Salina age. The bearing of these facts on the paleogeography of Siluric time was presented.

NOTES ON THE ONTARIC, OR SILURIC, SECTION OF EASTERN NEW YORK

BY C. A. HARTNAGEL*

[*Abstract*]

The Cobleskill limestone is the term applied to the Coralline limestone of Hall. Its stratigraphic position is just above the Salina. In southeastern New York and New Jersey the Cobleskill grades into the highly fossiliferous Decker Ferry formation. The occurrence of Eurypterus in western New York, in strata between beds which contain representatives of the Cobleskill fauna, shows that the Decker Ferry fauna lived in eastern New York before the Eurypterus fauna had entirely been replaced in western New York. Since the Cobleskill is above the Salina, the so-called Clinton quartzites, Medina shales, and the Shawangunk grit of eastern New York may be regarded as Salina in age.

The paper was discussed by J. M. Clarke, H. M. Ami, Gilbert van Ingen, and A. W. Grabau.

PALEOGRAPHY OF SAINT PETER TIME

BY CHARLES P. BERKEY

STRATIGRAPHY OF THE UINTA MOUNTAINS

BY CHARLES P. BERKEY

Remarks were made by H. M. Ami. The paper is printed as pages 517–532 of this volume.

HELDERBERG SEAS AND RELATIONSHIP OF LOWER DEVONIC STRATA OF EASTERN UNITED STATES

BY A. W. GRABAU

The paper was discussed by Stuart Weller, Charles Schuchert, Gilbert van Ingen, H. M. Ami, H. S. Williams, and B. K. Emerson.

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* Introduced by A. W. Grabau.

In the absence of the authors the remaining papers were read by title, in general session.

OCCURRENCE OF GEM MINERALS IN SAN DIEGO, RIVERSIDE, AND SAN BERNARDINO COUNTIES, CALIFORNIA

BY GEORGE F. KUNZ

The paper will be published by the California State Mining Bureau.

ROCKS OF MOUNT DESERT ISLAND, MAINE

BY PERSIFOR FRAZER

In general terms it may be said that Mount Desert island is the remains of an area, once much higher than now, which is distinguished by a series of narrow elevations and valleys of which the axes are nearly parallel and trend a little west of north and east of south. The northern and southern and western shores are low lands, though generally showing a rolling surface; but the easternmost edge of the island, and especially a zone which traverses the island a little below its mid-latitude, running about east 25 degrees north and west 25 degrees south, exhibits bold heights which have received the names of mountains, though none of them exceeds 1,555 feet by the Coast Survey levels. (The highest point of Green mountain from two sets of uncorrected barometer observations made by me in favorable weather gave a mean of 1,565 feet from the steamer wharf at Bar harbor to the foot of the U. S. Coast and Geodetic Survey signal on the summit.) Passing over this zone from east to west, we have Newport and its associated Picket mountains, Dry mountain, Green mountain, Pemetic mountain, The Bubbles, Jordan mountain, Sargent mountain, Little Browns mountain, Browns mountain, Robinson and Dog mountains, Beech mountain, and Western mountain with its two peaks divided by a deep ravine. The island is about fifteen minutes of latitude in extent north and south and about the same number of minutes of longitude in breadth east and west, including Bartlett and Hardwood islands; the average distance apart of its elevated ridges on the line of its greatest breadth is little more than a mile. Its structure can not be considered separately from the main land, to which the island is joined by a bridge at Trenton, and it evidently represents a survival of the southern edge of part of the coast due to the hard and resistant rocks of which it consists, and which have conferred upon it the distinction of the most elevated land on the Atlantic coast within the domain of the United States.

The principal sources from which information may be gathered as to the geology of Mount Desert island are W. O. Crosby's paper on the geology of Frenchmans bay,* N. S. Shaler's beautifully illustrated report on the Geology of Mount Desert,† and the introduction to the Flora of Mount Desert, Maine, by W. M. Davis.‡

Professor Shaler recognizes:

I. (1.) A gnarled and thick deposit of chloritic schists on the west side of the island.
  (2.) A nearly similar but less distinctly schistose terrane on the east side between Schooner head and Rodicks cove.

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* Vol. xxi, pp. 109-117, Proc. Bos. Soc. Nat. Hist.

† 8th Annual Report of the U. S. Geological Survey, part ii, 1886-'7, pp. 993 to 1061.

‡ Rand and Redkeld: John Wilson and Son, Cambridge, Mass.

(3.) Highly metamorphosed slates and flags with bedded felsites between them, occurring at Suttons and Cranberry islands and along the south shore.

(4.) Similar flags, slates, and granite with magnesian rocks on the north shore from Rodicks cove to the "Ovens."

(5.) Stratified volcanic breccias, porphyries, and ash beds found only south of Southwest harbor.

II. (1.) The great granite dike forming the massive of the several elevations of mountains and mounts traversing the island in a direction west 25 degrees south, together with smaller connected and disconnected intrusions.

(2.) The felsite porphyry dikes.

(3.) Dense dark colored "dike stones" which occupy the entire area of the main and outlying islands. They are much narrower, and so numerous that any line of 1,000 feet east and west will cut several of them.

(4.) A rare greenish trap. These several dikes have the most various strikes. Nine-tenths of them are the ordinary dark colored trappean materials common throughout the metamorphosed districts of New England. The larger and more numerous dikes have a strike of northeast and southwest, while the smaller number have directions about at right angles to this course.

(5.) Short dikes of white quartz "which seem to have been injected in a molten state and not deposited from solution in heated waters."

Professor Shaler ascribes the isolation and lack of continuity of the sedimentary rocks mentioned under I to causes which operated before they were divided by the granites—in other words, by erosion previous to the appearance of the igneous rocks. The interpenetration of the granite in minute threads proves that it must have been very fluid and consequently encased in rock. This conclusion draws the other that a vast but unknown amount of erosion must have taken place since the injection of the granite.

Essentially, Professor Davis agrees with Professor Shaler as to the probable relative age of the schists and flags and the likelihood that these sedimentary rocks represent the Cambrian or earlier. He recognizes, however, that all the rocks of the island are traversed in one place or another by the trap dikes.

It is worthy of note that on the south slope of Green mountain, about half a mile from the summit, is a knob or lesser summit, which, in a section made over the mountain from north to south is the first exhibition of a massive dike of basalt. Contacts with the pegmatite or granite are numerous, and the vent through which this mass of basic igneous rock reached the present surface seems to lie wholly within the granite mass. Moreover, the filaments of this basalt cut, intersect, and inclose the granite exactly as the granite in other localities is seen to cut, interpenetrate, and inclose fragments of the clastics through which it has passed.

Thin-sections of these rocks have been kindly made for me by Dr H. W. Wiley, director of the Chemical Bureau of the Department of Agriculture, and are here submitted for the inspection of the petrographers.

From Green and Sargent mountains

1. Gabbro-diabase.—Predominating labradorite, with diallage, magnetite, zoisite, augite, mostly in traces, crystals of both chief constituents idiomorphic. Very much altered. From Green Mountain knob, ± ½ mile south of summit.

2. Crypto-crystalline chloritic schist, with serpentine and various secondaries. Fragment from summit of Sargent mountain.

3. Weathered dolerite, very much altered; plagioclase (labradorite), very much decomposed; ferro-magnesian mineral; serpentine and chlorite. From south slope of Green mountain.

4. Chlorite schist, with many subordinate constituents. Fragment from south slope of Green mountain.

5. Weathered granite (pegmatite); quartz, with cavities, some containing liquid; feldspar, much kaolinized; some biotite. From Great Snake flat, south of Green mountain.

6. Basalt (diabase), with magnetite and chlorite. From Great Snake flat, Green mountain.

7. Metamorphosed ferruginous sandstone with primary quartz. Fragment (?). From summit of Sargent mountain.

8. Very fine grained devitrified rock. From Green Mountain knob, ± half a mile south of the summit.

From the north shore

I. Light aphanitic felsite with localities showing quartz; fine grained. The smaller grains rounded, while the larger are more frequently angular. The principal large constituent is mica (biotite). From dike near the Ovens.

II. Diabase with interlaced labradorite blades; augite predominating over feldspar; magnetite. From dike half a mile east of the Ovens.

III. Dolerite but little altered; augite, labradorite, magnetite, and probably olivine. From dike between the Ovens and Parkers point.

IV. Unaltered feldspathic fine grained granite, the crystals sharp-edged and well defined; fine grained white granite dike. From Hulls cove, northeast shore.

V. Quartzite with decomposed material between the grains. Some larger grains rounded and smaller grains angular. From between the Ovens and Parkers point.

VI. Quartzite with biotite; magnetite; a clastic metamorphosed by heat—not fused. From massive quartzite between the Ovens and Parkers point, dip north 20 degrees east, 80 degrees, the rock enclosing ovoid nodule whose long axis corroborated the conclusion as to bed plane.

VII. Very fine grained felsite. From dike between Ovens and Parkers point.

VIII. Very fine grained felsite. From Hayns point near the Ovens.

PLUMOSE DIABASE AND PALAGONITE FROM THE HOLYOKE TRAP-SHEET

BY B. K. EMERSON

The paper is printed as pages 91–130 of this volume.

DETERMINATION OF BRUCITE AS A ROCK CONSTITUENT

BY ALEXIS A. JULIEN

[*Abstract*]

Reference is first made to the increasing number of rock outcrops at which brucite is a notable accessory or an essential or even predominant constituent, in one recent instance 60 per cent.

The published data for its recognition by the petrographer are yet limited, insufficient, and in some respects inaccurate.

No reference to twinning is made in the general descriptions, but twins undoubtedly occur, having been noted in brucitic limestone (predazzite).

Inclusions, though rare, comprise red and black particles of iron oxides and black needles, and, at one locality, abundant seams or bands of liquid cavities.

The eminent basal cleavage is the only one recorded, but a distinct rhombohedral cleavage also commonly occurs, and also a third cleavage in traces.

The parting passes progressively at most localities from a ribbon-like banding to a fasciculate structure. A distinct fibration marks the steps of molecular rearrangement of foliated into fibrous brucite (nemalite).

The percussion figure, as produced by a needle, is characteristic for the mineral, partly for the rays diverging at 60 degrees and 30 degrees (as shown by O. Mügge), but mainly for the indentation or pit, which may be 6, 8, or 12 sided (a negative dihexagonal pyramid), and for a peculiar border of overlapping zones, circular, or sometimes hexagonal. The uniaxial interference-figure, obtained in convergent light, is disturbed in vicinity of the pit, opening into a biaxial figure whose axial plane, in positions around the pit, is found to radiate from that center.

The low refractive index of brucite facilitates its distinction by the Becke method from a number of its common mineral associates.

Its strong and positive birefringence, the directions of its two axes of depolarization, and its interference-figure, easily obtained, especially in cleavage flakes of the mineral, sometimes when enclosed in rocks, are characteristic toward recognition of brucite.

The marked strain phenomena of the mineral are described, but the strain *bands* have been found at only one or two localities, and can not be depended on for determination of the mineral, as might be inferred from some statements, though the disturbance of the interference figure is of general occurrence.

The peculiarities of nemalite proper are described, and of the distinction of two classes of its fibers, and of the effects of flexure, torsion, and strain on its optical properties. The common distribution of nemalite is explained.

The intimate interlamination of brucite and serpentine are described and the methods for establishing this rather difficult discrimination.

The chemical methods for its detection are then considered, particularly Lemberg's test with silver nitrate solution, and a simpler and more accurate modification proposed.

The etch-figures by weak acids are found to show characteristic features, though akin to those of dolomite. When mature, the rhombohedral cleavage becomes beautifully etched out.

A complete bibliography of the mineral is appended to the paper.

ORIGIN OF LEACHED PHOSPHATE

BY C. H. HITCHCOCK

PETROGRAPHY OF THE AMPHIBOLITE, SERPENTINE, AND ASSOCIATED ASBESTOS DEPOSITS OF BELVIDERE MOUNTAIN, VERMONT

BY V. F. MARSTERS

The paper is printed as pages 419–446 of this volume.

SHIFTING OF THE CONTINENTAL DIVIDE AT BUTTE, MONTANA

BY W. H. WEED

[*Abstract*]

This paper discusses the faulting and tilting of the fault blocks immediately east of Butte, Montana, with the accompanying reversal of drainage, filling of broad and deep valleys by imponded wash and debris, the formation of the so-called Tertiary lake deposits, and the change of the groundwater level, affecting the mineral deposits of Butte. The peculiar physiographic features near Butte are discussed, namely, the fault scarp of the east ridge, the distributed faulting making zones of easy erosion and leaving the harder, unbroken granite as foothill knobs in peculiar prominence. The great flat at Butte is shown to be an old valley leveled by the wash of torrents, and the peculiar mountain basin known as Elk park, which now drains into the Atlantic, is shown to be the headwater portion of a valley whose eastern end has been faulted and tilted northward. The facts presented in this rather limited area apply to the remarkable series of north and south valleys filled with alluvial and supposedly lacustrine sediments found throughout the mountainous region of Montana.

NANTUCKET SHORELINES, III, MUSKEGAT

BY F. P. GULLIVER

RELATION OF LAKE WHITTLESEY TO THE ARKONA BEACHES

BY FRANK B. TAYLOR

[*Abstract*]

Recent investigations in southeastern Michigan have disclosed a new and somewhat peculiar episode in the Great Lake history. Lake Maumee was the earliest and highest of the glacial lakes in the Erie-Huron basin. It is found that when this lake was drained off the waters fell to the level of the upper beach of lake Arkona, and that at the close of this lake's existence the ice-front readvanced, pushing the point of discharge up the crest of the thumb, thereby closing the earlier outlet and raising the waters to the level of the Belmore beach of lake Whittlesey. In this way the Arkona beaches became submerged, and they remained in that state during the existence of lake Whittlesey. The paper sets forth the facts which show this history. The general relations may be epitomized thus—the Port Huron-Saginaw moraine marks the position of the ice barrier which

retained lake Whittlesey. The outlet of the lake was through the Ubly channel, close along the frontal base of the moraine, in the angle where it laps around the crest of the thumb. In Wayne county the Belmore beach is 738 to 740 feet above sealevel, and the Arkona beaches– three in number—are close to 708, 702, and 696 feet.

The principal evidences may be summarized as follows:

1. The Belmore beach was not found on the back or iceward slope of the Port Huron-Saginaw moraine; neither is there any distinct beach, but only scattered fragments of outwash at the Belmore level on the frontal slope of the moraine.

2. The Arkona beaches are below the Belmore level and too low to connect with the Ubly channel, and yet there is no sign of any of them on either slope of the moraine. This shows that the Arkona beaches antedate the moraine and were not formed after the fall of lake Whittlesey. On the other hand, the Upper Forest beach, which lies next below the Arkona ridges, was found strongly developed on both slopes of the moraine and is the highest shoreline recorded on it. This beach passes around the end of the thumb into the Saginaw valley.

3. Lake Whittlesey terminated at the north in a shallow, rather narrow bay nearly 50 miles long. The entrance to this bay was northeast of Avoca, between Spring hill and the moraine 4 miles east. South of this bay, where the heavy seas of lake Whittlesey swept over the submerged Arkona ridges with full force, these ridges show unmistakable evidences of modification. They are so flattened that they are more easily traced by characters of composition than by their relief as ridges. The soils on them and on the river deltas associated with them are clayey and stiff as compared with the soils of the Belmore and Maumee beaches. While the ridges appear in fair strength at some points south of Avoca, they are in general very faint and hard to trace. They were almost washed away and destroyed during the time of submergence.

4. North of the entrance to the bay at Spring hill the three Arkona ridges undergo a complete change of character. Within a mile or two they grow strong and fully equal to the best development of the Maumee beaches and almost equal to the Belmore. They are 100 to 400 feet wide at their bases and 6 to 10 feet high. Fragments of the lower ridge were found on the east side of Black river and with the foot of the moraine resting directly against their bases, leaving only a narrow depression, 4 or 5 feet deep, between. In two or three paces one may step from the sandy gravel of the beach to the stony clay of the moraine. These fragments have almost no lake sediment or outwash on them, though farther north all three ridges are buried under fine sandy outwash from the moraine. The lower ridge was traced 6 miles north from Spring hill, the middle ridge 14 miles, and the upper ridge 18 miles. These beach ridges could not have been formed in their present surroundings. The massive moraine east of Black river and the glacier which made it could not have been present. The ice-front must have stood several miles farther north and east. It seems plain that the Arkona beaches antedate the moraine.

5. The Arkona beaches appear to have been made by a lake which was falling by stages. The Belmore, on the other hand, gives evidence of having been made by a rising lake, for its material appears to have been shoved up the slope while it was being built. The Belmore beach appears to rest on a drift surface which was previously trenched by streams. Where the Arkona ridges lay in the bay north of Spring hill they were protected from disturbance by heavy seas, and such parts

as were neither overridden by the moraine nor buried under outwash remained unchanged after the fall of lake Whittlesey; but southward from Spring hill the submerged ridges were greatly modified—almost obliterated—by the storm waves which swept over them.

A longer abstract of this paper will be published in the Seventh Annual Report of the Michigan Academy of Sciences (1905), and it will be published in full in the Journal of Geology.

UPPER TRIAS OF THE LANDER BASIN, WYOMING

BY S. W. WILLISTON

RED BEDS OF SOUTHWESTERN COLORADO AND THEIR CORRELATION

BY WHITMAN CROSS AND ERNEST HOWE

This paper is printed as pages 447–498 of this volume.

GEOLOGY OF FISHERS ISLAND, NEW YORK

BY MYRON L. FULLER

The paper is printed as pages 367–390 of this volume.

PLEISTOCENE OF THE CHESAPEAKE AND DELAWARE BASINS

BY ARTHUR BIBBINS

THE LOESS OF THE LOWER MISSISSIPPI

BY G. FREDERICK WRIGHT

THE LOESS AND ASSOCIATED INTERGLACIAL DEPOSITS

BY B. SHIMEK

[*Abstract*]

The loess of this country has usually been referred to one period. This paper presents evidence of the existence of four distinct loesses in Iowa and adjacent territory—that is, post-Kansan, post-Illinoisan, post-Iowan, and post-Wisconsin. These loesses were not contemporaneous with the respective drifts, but followed the recession of the ice of each drift-period after an interval during which residual gravels and sand dunes or soils (all but the last now buried) were formed. Each post-Glacial period therefore produced residual gravels, sand dues or mucky soils, and finally loess.

The distribution and characters of the several interglacial deposits are discussed with special reference to the probable conditions of climate, drainage, and floral covering during the deposition or formation of each.

PELÉ AND THE EVOLUTION OF THE WINDWARD ARCHIPELAGO

BY ROBERT T. HILL

The paper is printed as pages 243–288 of this volume.

The President declared the scientific program closed.

The report of the Photograph Committee was presented as follows:

FIFTEENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

During the past year there have been no additions to the collection of photographs, but, through the kindness of the Director of the Geological Survey, many new prints of old views have been made and mounted on muslin. By this means the quality of the collection has been materially improved and its bulk greatly reduced. The collection has remained stored in my office, in Washington, very convenient of access at all times. A number of prints have been ordered from time to time, by various persons, for teaching and the illustration of scientific papers.

Respectfully submitted,

N. H. Darton,
Committee.

The report was adopted, and the usual appropriation of $15 for the use of the committee was voted.

RESOLUTION OF THANKS

The following resolution of thanks, offered by A. C. Lane, was unanimously adopted:

Resolved, That the Geological Society of America, assembled in seventeenth annual meeting, hereby expresses gratitude to the officers of the University of Pennsylvania, to the local committee of the American Association for the Advancement of Science, and to the citizens of Philadelphia for their hospitality, which has made a large and successful meeting extremely pleasant; that special thanks be extended to Professor A. P. Brown and the Geological Department of the University for the use of the convenient rooms and facilities for illustration, and to the local committee for the convenience and social opportunity of the daily lunch.

After announcements the meeting was declared adjourned.

Register of the Philadelphia Meeting, 1904

The following Fellows were in attendance at the meeting:

F. D. Adams.
H. M. Ami.
H. F. Bain.
Florence Bascom.
Robert Bell.
C. P. Berkey.
J. C. Branner.
A. P. Brigham.
A. H. Brooks.
Samuel Calvin.
W. B. Clark.
J. M. Clark.
A. P. Coleman.
A. J. Collier.
Whitman Cross.
E. R. Cumings.
H. P. Cushing.
N. H. Darton.

W. M. Davis.
D. T. Day.
J. S. Diller.
R. E. Dodge.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
Persifor Frazer.
M. L. Fuller.
Henry Gannett.
G. K. Gilbert.
A. C. Gill.
A. W. Grabau.
H. E. Gregory.
Arnold Hague.
C. W. Hayes.
Angelo Heilprin.
R. T. Hill.
Arthur Hollick.
T. C. Hopkins.
E. O. Hovey.
Ernest Howe.
E. E. Howell.
J. P. Iddings.
J. F. Kemp.
E. H. Kraus.
H. B. Kümmel.
A. C. Lane.
D. W. Langton.
C. K. Leith.
T. H. MacBride.
G. C. Martin.
E. B. Mathews.
P. H. Mell.
G. P. Merrill.
W. G. Miller.
F. B. Peck.
G. H. Perkins.
Raphael Pumpelly.
H. F. Reid.
W. N. Rice.
Heinrich Ries.
I. C. Russell.
Charles Schuchert.
G. B. Shattuck.
E. A. Smith.
G. O. Smith.
J. W. Spencer.
J. Stanley-Brown.
T. W. Stanton.
R. S. Tarr.
C. D. Walcott.
H. S. Washington.
T. L. Watson.
Stuart Weller.
L. G. Wesgate.
David White.
I. C. White.
R. P. Whitfield.
H. S. Williams.
Bailey Willis.
S. W. Williston.

Fellows-elect.

N. M. Fenneman.
Ralph Arnold.
B. L. Miller.
M. S. W. Jefferson.
Gilbert van Ingen.

Total attendance, 85.

SESSION OF THE CORDILLERAN SECTION, FRIDAY, DECEMBER 30, 1904

The sixth annual meeting of the Cordilleran Section of the Society was called to order at 10.30 a m, December 30, 1904, in South Hall, Berkeley.

The chairman of the section, Professor E. W. Hilgard, presided.

The minutes of the last meeting were read and approved.

The following officers were elected for the ensuing year: W. G. Tight, Chairman; George D. Louderback, Councillor; Andrew C. Lawson, Secretary.

The Committee on Resolutions submitted the following resolution, which was adopted and ordered spread upon the minutes:

> The Cordilleran Section of the Geological Society of America desires to express and record its grief at the loss by death of one of its most active members, Professor Wilbur C. Knight, of Laramie, Wyoming. In his untiring energy, his wide scientific interests, and in his fine cooperative spirit he was a notable figure in the small band of geologists at work in the Cordilleran region of North America. His death, in the prime of life, is a great loss to geological science and to the fellowship of the Society.

The following papers were then read and discussed:

MOST PRIMITIVE TYPE OF ICHTHYOSAURIAN LIMB

BY JOHN C. MERRIAM

Published as Bulletin of the Department of Geology, University of California, volume 4, number 2.

RELATIONSHIPS OF ARCTOTHERIUM

BY JOHN C. MERRIAM

NEW SHEEP-LIKE FORM FROM THE SAMWEL CAVE

BY E. L. FURLONG *

Published as Bulletin of the Department of Geology, University of California, volume 4, number 8.

The Section then adjourned for luncheon.

At 2 p m the session was resumed and the following papers were read:

STUDY OF THE STRATIGRAPHY AND STRUCTURE OF THE MOUNT DIABLO RANGE

BY F. M. ANDERSON

Published in the Proceedings of the California Academy of Sciences, third series, Geology, volume 2, number 2, pp. 156–244.

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* Introduced by John C. Merriam.

SOME PECULIARITIES OF ROCK WEATHERING AND SOIL FORMATION IN THE ARID REGION

BY E. W. HILGARD

GEOLOGY OF THE MINERAL KING BELT

BY A. KNOPF AND P. THELEN*

Published as Bulletin of the Department of Geology, University of California, volume 4, number 12.

The Section then adjourned till next morning.

SESSION OF THE CORDILLERAN SECTION, SATURDAY, DECEMBER 31

The Section was called to order at 10 a m, Professor E. W. Hilgard in the chair.

The following papers were read and discussed :

A DETAIL OF THE GREAT FAULT ZONE OF THE SIERRA NEVADA

BY JOHN A. REID*

[*Abstract*]

The writer has been led to this subject by his study of the contact metamorphism of the granite and slate on the east flank of the Sierra. The particular locality described in this paper is just west of Franktown, in Washoe county, Nevada. The rocks, following Turner, are: (1) the basement complex of granite intrusive in Jurassic (?) slate; and (2) a superjacent series, of volcanics (rhyolite and andesite) with the gravels of a Tertiary river channel which runs approximately northeast-southwest. A longitudinal north-south fault valley, called Little valley, with almost ideal cross-section, exists here about 1,400 feet above the floor of Washoe valley. From the lower valley the first fault scarp rises 1,500 feet, the crest being the eastern limit of Little valley. On the west the second scarp rises unbroken for 2,000 feet to the crest of the range. The two faults are of different ages, shown by the physiographic features, the lower being the older. East and west faulting also occurs, tending to shift both north-south faults eastward, as well as to make the faulting multiple. Small hanging fault blocks, allied to the "kernbuts" of Professor Lawson, are very noticeable on the upper scarp to the north. The river gravels, being on a basement broken by more complex faulting, show well the character of the movements—in the main a north-south series of normal faults of at least two ages.

CERTAIN FORMATIONS OF SOUTHWESTERN OREGON

BY GEORGE D. LOUDERBACK

Published in the Journal of Geology, volume 13, number 6, 1905, pp. 514–555.

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* Introduced by Andrew C. Lawson.

CONTRIBUTION TO THE PALÆONTOLOGY OF THE MARTINEZ GROUP

BY CHARLES E. WEAVER*

Published as Bulletin of the Department of Geology, University of California, volume 4, number 5.

The Section then adjourned for luncheon.

At 2 p m the Section reassembled to hear the reading of the following papers:

GEOLOGY OF THE ROBINSON MINING DISTRICT, NEVADA

BY ANDREW C. LAWSON

ARCAS OF THE CALIFORNIA TERTIARY

BY VANCE C. OSMONT*

Published as Bulletin of the Department of Geology, University of California, volume 4, number 4.

The following papers were read by title:

STREAM PIRACY IN THE UPPER PECOS, NEW MEXICO

BY W. G. TIGHT

BASAL STRUCTURE OF THE SANDIA MOUNTAINS, NEW MEXICO

BY W. G. TIGHT

LAWSONITE

BY A. S. EAKLE

The Section then adjourned.

Andrew C. Lawson,
Secretary.

Register of the Meeting of the Cordilleran Section

The following named Fellows were in attendance at the meeting:

E. W. Hilgard.
George D. Louderback.
F. M. Anderson.
R. H. Loughridge.
J. C. Merriam.
A. S. Eakle.
W. S. T. Smith.
A. C. Lawson.

The visitors were:

E. L. Furlong.
V. C. Osmont.
C. E. Weaver.
A. Knopf.
J. C. Hartzell.
E. P. Carey.

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*Introduced by John C. Merriam.

ACCESSIONS TO THE LIBRARY FROM JULY, 1904, TO JULY, 1905

BY H. P. CUSHING, *Librarian*

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(*A*) FROM SOCIETIES AND INSTITUTIONS RECEIVING THE BULLETIN AS DONATION ("EXCHANGES")

(*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

2655–2658. Museum Report 55, parts 1–4.
2485. Bulletin 63.
2659–2660. Bulletins 73–76 and 79.

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

2328. Proceedings, vol. xxxi, nos. 8–10.
2620. " " xxxii, nos. 1–4.

MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

2618. Anales, serie iii, tomo 3.

CHICAGO ACADEMY OF SCIENCES, CHICAGO

FIELD COLUMBIAN MUSEUM, CHICAGO

2402. Geological series, vol. ii, nos. 5–6.
2598–2599. Zoological series, vol. iv, parts 1–2.
2181. Report series, vol. ii, no. 4.
2715. Geological series, vol. iii, no. 1.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

COLORADO SCIENTIFIC SOCIETY, DENVER

2398. Separate papers from Proceedings, vol. vii.

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

MUSEO DE LA PLATA, LA PLATA

CUERPO DE MINAS DEL PERU, LIMA

2559. Boletin, nos. 5–7, 10–13, 15–17.

INSTITUTO GEOLOGICO DE MEXICO, MEXICO
2504. Parergones, tomo 1, num. 2-8.

NATURAL HISTORY SOCIETY OF MONTREAL, MONTREAL

AMERICAN GEOGRAPHICAL SOCIETY, NEW YORK
2542. Bulletin, vol. xxxvi, nos. 6-12, 1904.
2649. " " xxxvii, nos. 1-6, 1905.

AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK
2226. Bulletin, vol. xviii, part 3.
2653. Bulletin, vol. xx.
2654. Memoirs, vol. iii, part 3.
2676. Album of Philippine Types.

NEW YORK ACADEMY OF SCIENCES, NEW YORK
2083. Annals, vol. xiv, parts 2-3.
2443. " " xv, part 3.
2696. " " xvi, part 1.
1769. Memoirs, vol. ii, parts 3-4.

AMERICAN INSTITUTE OF MINING ENGINEERS, NEW YORK
2627. Transactions, vol. xxxiv, 1903.

GEOLOGICAL SURVEY OF CANADA, OTTAWA
2629. Annual Report, new series, vol. xiii, 1900.
2124. Catalogue of Canadian Birds, part 3, 1904.

ROYAL SOCIETY OF CANADA, OTTAWA
2592. Proceedings and Transactions, second series, vol. ix.

ACADEMY OF NATURAL SCIENCES, PHILADELPHIA
Proceedings, vol. lvi, parts 1-3, 1904.

AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA
2526. Proceedings, vol. xliii, 1904.
2647. Transactions, vol. xxi, part i.

MUSEO NACIONAL DE RIO DE JANEIRO, RIO DE JANEIRO

CALIFORNIA ACADEMY OF SCIENCES, SAN FRANCISCO
1282. Proceedings, 3d series, Geology, vol. i, no. 10.

GEOLOGICAL SURVEY OF NEWFOUNDLAND, ST JOHNS
2663. Reports on the Mineral Statistics and Mines for 1898-1903.
2693. Reports for the years 1871-1872, 1875-1879, 1881, 1891-1892.

ACADEMY OF SCIENCE, ST LOUIS
2541. Transactions, vol. xiv, nos. 1-8.

COMMISSAO GEOGRAPHICA E GEOLOGICO, SAO PAULO

NATIONAL GEOGRAPHIC SOCIETY, WASHINGTON
2461. National Geographic Magazine, vol. xv, nos. 7-12, 1904.
2643. " " " " xvi, nos. 1-6, 1905.

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SMITHSONIAN INSTITUTION, WASHINGTON

2631. Annual Report, 1903.

UNITED STATES GEOLOGICAL SURVEY, WASHINGTON

2539. Professional Papers 21–23.
2613–2614. “ “ 24–31 and 33.
2535. Bulletins 226–229.
2593. “ 230–234, 236, 240.
2594–2595. Water Supply Papers 88–96.
2615. “ “ “ 101–103.
2642. Monograph 47.

UNITED STATES NATIONAL MUSEUM, WASHINGTON

(*b*) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

2438. Zeitschrift, band lv, heft 4, 1903.
2622. “ “ lvi, heft 1–3, 1904.
2636. Register, bande 1–50, 1848–98.

KÖNIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

2600. Jahrbuch, band xxii, 1901.

GEOGRAPHISCHEN GESELLSCHAFT, BERNE

2586. Jahresbericht, band xviii, 1900–2.

SCHWEIZ GEOLOGISCHEN KOMMISSION, BERNE

2644. Lieferung xiv, neue folge.
2645. “ iii, Geotechnische serie.
2716. “ xvii–xix, neue folge.

R. ACCADEMIA DELLE SCIENZE DELL' INSTITUTO DI BOLOGNA, BOLOGNA

2608–2609. Rendiconto, nuova serie, vols. v–vi.
2610. Memorie, serie v, tomo ix.

NATURHIST. VEREINS DES PREUSSISCHEN RHEINLANDE, WESTFALENS, UND DES REG.-BEZIRKS OSNABRÜCK, BONN

2510. Sitzungsberichte der Niederrhein. Gesellschaft, 1904, hälfte 1.
2666. Verhandlungen, 1904, hälfte 1.

ACADÉMIE ROYALE DES SCIENCES, DES LETTERS, ET DES BEAUX-ARTS DE BELGIQUE, BRUSSELS

2544. Bulletin de la Classe des Sciences, 1904.
2700. Annuaire, 1905.

SOCIÉTÉ BELGE DE GÉOLOGIE, DE PALÉONTOLOGIE, ET D'HYDROLOGIE, BRUSSELS

2587. Bulletin, tome xviii, 1904.

BIUROULI GEOLOGICA, BUCHAREST

1435. Harta Geologica generala a Romaniei, sheets 26–7, 29 bis, 35 and 35 bis.

MAGYARHONI FÖLDTANI TARSULAT, BUDAPEST

2628. Földtani közlöny, xxxiv kötet, 1–10 fuset, 1904.

NORGES GEOLOGISKE UNDERSOGELSE, CHRISTIANA

DANMARKS GEOLOGISKE UNDERSOGELSE, COPENHAGEN

DET KONGELIGE DANSKE VIDENSKABERNES SELSKAB, COPENHAGEN

2530. Oversigt i Aaret, Förhandlingar, 1904, nos. 2–6.
2701. " " " " 1905, no. 1.

NATURWISSENSCHAFTLICHEN GESELLSCHAFT ISIS, DRESDEN

2632. Sitzungsberichte und Abhandlungen, Jahrgang 1904.

ROYAL SOCIETY OF EDINBURGH, EDINBURGH

NATURFORSCHENDEN GESELLSCHAFT, FREIBURG I. B.

2640. Berichte, band xiv, 1904.

GEOLOGICAL SOCIETY OF GLASGOW, GLASGOW

KSL. LEOP. CAROL. DEUTSCHEN AKADEMIE DER NATURFORSCHER, HALLE

2522–2523. Nova Acta, bande 80–81.
2524. Leopoldina, heft 37–39.

COMMISSION GÉOLOGIQUE DE FINLANDE, HELSINGFORS

SOCIÉTÉ DE GÉOGRAPHIE DE FINLANDE, HELSINGFORS

SCHWEIZISCHE GEOLOGISCHE GESELLSCHAFT, LAUSANNE

GEOLOGISCH REICHS-MUSEUM, LEIDEN

2331. Sammlungen, band vii, heft 3.
2646. " " viii, heft 1.

K. SÄCHISCHE GESELLSCHAFT DER WISSENSCHAFTEN, LEIPZIG

2414. Abhandlungen der math.-phys. Classe, band xxviii, nos. 6–7.
2413. Berichte, Jahrgang 1903, heft 6.
2590. " " 1904, heft 1–3.
2650. Abhandlungen der math.-phys. Classe, band xxix, no. 1.

SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE, LIÈGE

2514. Annales, tome xxxi, livr. 2–3, 1904.
2698. " " xxxii, livr. 1, 1905.
2607. Memoirs, tome ii, livr. 1, 4to.

SOCIÉTÉ GÉOLOGIQUE DU NORD, LILLE

2588. Annales, tome xxxii, 1903.

COMMISSAO DOS TRABALHOS GEOLOGICOS DE PORTUGAL, LISBON

2694. Communicacoes, tome v, 1903–1904.

BRITISH MUSEUM (NATURAL HISTORY), LONDON

2623. Guide to fossil Mammals and Birds, 1904.
2624. Introduction to Study of Meteorites, 1904.
2625. Catalogue of Jurassic Plants, part 2, 1904.

GEOLOGICAL SOCIETY, LONDON

2499. Quarterly Journal, vol. lx, parts 3-4, 1904.
2678. " " " lxi, part 1, 1905.
2602. Geological Literature, 10.

GEOLOGICAL SURVEY, LONDON

2591. Memoir, Tertiary Igneous Rocks of Skye.
2626. " Summary of Progress, 1903.
2648. " Water Supply of Lincolnshire.
2652. Handbook to British Minerals.
2710. Memoir, North Staffordshire Coalfields.

GEOLOGISTS' ASSOCIATION, LONDON

2353. Proceedings, vol. xviii, parts 7-10.
2705. " " xix, part 1.

COMISION DEL MAPA GEOLOGICA DE ESPAÑA, MADRID

2635. Memorias, tomo v, Sistemas Infracretaceo y Cretaceo, 1904.

SOCIETA ITALIANA DI SCIENZE NATURALI, MILAN

2520. Atti, vol. xliii, fasc. 1-4, 1904.

SOCIÉTÉ IMPERIALE DES NATURALISTES DE MOSCOU, MOSCOW

2427. Bulletin, Année 1903, no. 4.
2606. " " 1904, no. 1.

K. BAYERISCHE AKADEMIE DER WISSENSCHAFTEN, MUNICH

2496. Sitzungsberichte, math.-phys. Classe, 1903, heft 3-5.
2664. " " " " 1904, heft. 1-2.

ANNALES DES MINES, PARIS

2494. Annales, 6ᵉ serie, tome v, lief. 5-6, de 1904.
2604. " " " vi, lief. 7-12, de 1904.
2661. " " " vii, lief. 1-3, de 1905.

CARTE GÉOLOGIQUE DE FRANCE, PARIS

2437. Bulletin, vol. xiv, nos. 94-95.
2641. " " xv, nos. 96-99.

SOCIÉTÉ GÉOLOGIQUE DE FRANCE, PARIS

2545. Bulletin, 4ᵉ serie, tome iv, fasc. 1-5, 1904.
2352. " " " iii, fasc. 6, 1903.
2194. " " " ii, fasc. v, 1902.

REALE COMITATO GEOLOGICO D'ITALIA. ROME

2909. Bolletino, vol. xxxv, nos. 1-4, 1904.

SOCIETA GEOLOGICA ITALIANA, ROME

2528. Bolletino, vol. xxii, fasc. 1–2, 1903.
2589. " " xxiii, fasc. 1–2, 1904.

ACADÉMIE IMPERIALE DES SCIENCES, ST PETERSBURG

COMITÉ GÉOLOGIQUE DE LA RUSSIE, ST PETERSBURG

384. Memoirs, vol. xiii, no. 4.
1173. " " xv, no. 1.
2342. " " xix, no. 2.
2547–2548. " nouvelle serie, livr. 5–9.
2669–2672. " " " livr. 10–13.
2546. Bulletin, vol. 22.
2707. Region aurifère d'lénissei, feuilles K 7–8, L 6, 8–9 and texts.
2708. " " de Lena, feuille II 2, with text.

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2605. Verhandlungen, band xli, lief. 1–2.
2408. Materialen zur Geologie Russlands, band xxi, lief. 2.
2673. " " " " " xxii, lief. 1.

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2711. " " " " Aa, nos. 124, 127–8.
2712. " " " " A1, no. a1, with map.

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2313. Förhandlingar, band xxv, hafte 6, 1903.
2498. " " xxvi, hafte 5–7, 1904.
2668. " " xxvii, hafte 1–3, 1905.

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2501. Neues Jahrbuch, 1904, band i, heft 3.
2601. " " 1904, band ii, heft 1–3.
2695. " " 1905, band i, heft 1–2.
2502. Centralblatt, 1904, nos. 9–24.
2665. Centralblatt, 1905, nos. 1–9.

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2549, 2639. Jahrbuch, band liii, 1904, and band liv, 1905.

KAISERLICH-KÖNIGLICHEN NATURHISTORISCHEN HOFMUSEUMS, VIENNA

2621. Annalen, band xix, Nr. 1–3, 1904.

(c) *ASIA*

GEOLOGICAL SURVEY OF INDIA, CALCUTTA

2137. Memoirs, vol. xxxii, part 4.
2334. " vol. xxxv, part 3.
2633. " vol. xxxvi, part 1.
2634. Records, vol. xxxi, parts 1–3.

IMPERIAL GEOLOGICAL SURVEY, TOKYO

(d) *AUSTRALASIA*

GEOLOGICAL DEPARTMENT OF SOUTH AUSTRALIA, ADELAIDE

1515. Record of the Mines, Supplementary Report.
2527. Review of Mining Operations in S. A. during 1904.

GEOLOGICAL SURVEY OF QUEENSLAND, BRISBANE

2630. Reports 193–195.

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DEPARTMENT OF MINES OF VICTORIA, MELBOURNE

2317. Annual Report of the Secretary of Mines for 1903.
2532. Bulletins, nos. 13–17.
2344. Records, vol. i, part 3.
2651. Diagram showing yield of gold per annum, etcetera.

GEOLOGICAL DEPARTMENT OF WESTERN AUSTRALIA, PERTH

2463. Bulletins, nos. 11–14.
2138. Annual Progress Reports for 1901 and 1903.
2697. Bulletins, nos. 16–17.

GEOLOGICAL SURVEY OF NEW SOUTH WALES, SYDNEY

2603. Annual Report of the Department of Mines for 1903.
2044. Records of the Geological Survey, vol. vii, part 4.
2706. Memoirs, Paleontology, no. 13, part 1.
2713. Records, vol. viii, part 1.
2714. Annual Report of the Department of Mines for 1904.

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2702. Journal and Proceedings, vol. xxxvii, 1903.

(e) *AFRICA*

GEOLOGICAL COMMISSION, CAPE TOWN

2492. Annals of the South African Museum, vol. iv, parts 4–6.
2597. Annual Report for 1900.
2674. Index to Annual Reports, 1896–1903.

GEOLOGICAL SOCIETY OF SOUTH AFRICA, JOHANNESBURG

2677. Transactions, vol. vii, parts 1–3.

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2636. Report for the year 1903.

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2619. Second Report of the Geological Survey, 1904.

(*f*) *HAWAIIAN ISLANDS*

HAWAIIAN GOVERNMENT SURVEY, HONOLULU

(*B*) FROM STATE GEOLOGICAL SURVEYS AND MINING BUREAUS

UNIVERSITY OF TEXAS MINERAL SURVEY, AUSTIN

2550. Bulletins nos. 8–9.

GEOLOGICAL SURVEY OF OHIO, COLUMBUS

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DEPARTMENT OF THE INTERIOR, OTTAWA

2612. Topographic Maps; Windsor sheet, Ontario; map showing Stations of Mounted Police in Northwest Canada; map showing Railways in Manitoba, Saskatchewan, Alberta, etcetera.

NEW JERSEY GEOLOGICAL SURVEY, TRENTON

2611. Final Report, vol. vi, 1904; Clay Industry.

GEOLOGICAL SURVEY OF ALABAMA, UNIVERSITY

2719. Index to Mineral Resources of Alabama.

(*C*) FROM SCIENTIFIC SOCIETIES AND INSTITUTIONS

(*a*) *AMERICA*

BROOKLYN INSTITUTE OF ARTS AND SCIENCES, BROOKLYN

2720. Science Bulletin, vol. i, no. 4.

COLORADO COLLEGE, COLORADO SPRINGS

2555. Science series, Colorado College Studies, vol. xi, nos. 36–38.

SOCIEDAD CIENTIFICA "ANTONIO ALZATE," MEXICO

2203. Memorias y Revista, tomo xiii, num. 7–8.
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2721. First Report of the Bureau of Archives, 1903.

(*b*) *EUROPE*

SCHLESISCHE GESELLSCHAFT FÜR VATERLÄNDISCHE CULTUR, BRESLAU

2616. 81st Jahresbericht.
2617. Die Hundertjahrfeier, etcetera.

OBSERVATOIRE ROYALE DE BELGIQUE, BRUSSELS

2699. Annuaire Astronomique pour 1906.

NATURFORSCHER-VEREINS ZU RIGA, RIGA

2722. Korrespondenzblatt, xlvii, 1904.

R. ISPETTORATO DELLE MINIERE, ROMA

2723. Catalogo della Mostra fatta dal Corpo Realle delle Miniere all'Esposizione Universale di Saint Louis nel 1904.

SECTION GÉOLOGIQUE DU CABINET DE SA MAJESTÉ, ST PETERSBURG

2724. Travaux, vol. vi, livr. 1.

(*c*) *ASIA*

TOKYO GEOGRAPHICAL SOCIETY, TOKYO

2725. Journal of Geography, vol. xvi, 1904.

IMPERIAL UNIVERSITY OF TOKYO, TOKYO

2726. Journal of the College of Science, vol. xx, articles 2 and 5.

(*D*) FROM FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA (PERSONAL PUBLICATIONS)

H. L. FAIRCHILD

2727. Glacial Waters from Oneida to Little Falls.
2728. Geology under the Planetesimal Hypothesis of Earth-origin.

C. H. GORDON

2729. On the Origin and Classification of Gneisses.
2730. On the Paramorphic Alteration of Pyroxene to common Hornblende.
2731. Pyroxenites of the Grenville Series in Ottawa county, Canada.

C. H. HITCHCOCK

2732. Glaciation of the Green Mountains.
2733. New Studies in the Ammonoosuc District of New Hampshire.

R. G. McCONNELL

2734. Report on the great Landslide at Frank, Alta.

JOSEPH HYDE PRATT

2735. Ten Separates on the Production of Minerals in 1903.

ISRAEL C. RUSSELL

2736. The Topographic Survey of Michigan.
2737. Cooperation among American Geographical Societies.
2738. Research in State Universities.
2739. Physiographic Problems of Today.

SAMUEL WEIDMAN

2740. Baraboo Iron-bearing District. Bull. xiii, Wisconsin Geological Survey.

(*E*) From Miscellaneous Sources

G. SIMOENS, BRUSSELS

2741. Réponse aux Critiques formulées par M. Emm. de Margerie au Sujet de la Bibliographica Geologica.

MICHEL MOURLON, BRUSSELS

2742. Encore un Mot sur les Travaux du Service Geologique de Belgique.

FLORENTINO AMEGHINO, LA PLATA

2743. Paleontologia Argentina, no. 2.

ALEXANDER V. KALECSINSZKY, BUDAPEST

2744. Über die Akkumulation der Sonnenwärme in verschiedenen Flüssigkeiten.

FLORENTINO AMEGHINO, LA PLATA

2743. Paleontologia Argentina, no. 2.

MINING MAGAZINE NEW YORK

2745–2746. Mining Magazine, vol. x, nos. 1 and 5; vol. xi, no. 3.

G.-F. DOLLFUS ET G. RAMOND, PARIS

2747. Études géologiques dans Paris et sa Banlieue, iv.

WIRT TASSIN, WASHINGTON

2748. The Persimmon Creek and Mount Vernon Meteorites.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1905

President

Raphael Pumpelly, Dublin, N. H.

Vice-Presidents

Samuel Calvin, Iowa City, Iowa
W. M. Davis, Cambridge, Mass.

Secretary

H. L. Fairchild, Rochester, N. Y.

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J. Stanley-Brown, Washington, D. C.

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(Term expires 1905)

R. D. Salisbury, Chicago, Ill.
J. E. Wolff, Cambridge, Mass.

(Term expires 1906)

John M. Clarke, Albany, N. Y.
George P. Merrill, Washington, D. C.

(Term expires 1907)

H. M. Ami, Ottawa, Canada
J. F. Kemp, New York city

FELLOWS IN DECEMBER, 1905

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., 1441 Florida Ave. N. W., Washington, D. C. August, 1899.

Frank Dawson Adams, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

George I. Adams, Sc. D., Corps of Mining Engineers, Lima, Peru. December, 1902.

José Guadalupe Aguilera, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

Truman H. Aldrich, M. E., 1739 P St. N. W., Washington, D. C. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Frank M. Anderson, B. A., M. S., 2604 Ætna Street, Berkeley, Cal. In California State Mining Bureau. June, 1902.

Philip Argall, 728 Majestic Building, Denver, Colo.; Mining Engineer. August, 1896.

Ralph Arnold, Ph. D., Washington, D. C.; Geologic Aid U. S. Geological Survey. December, 1904.

George Hall Ashley, M. E., Ph. D., Washington, D. C., U. S. Geological Survey. August, 1895.

Harry Foster Bain, M. S., Champaign, Ill., State Geological Survey. December, 1895.

Rufus Mather Bagg, Ph. D., Socorro, N. Mex.; Professor of Mineralogy and Petrography, State School of Mines. December, 1896.

S. Prentiss Baldwin, 736 Prospect St., Cleveland, Ohio. August, 1895.

Erwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

Joseph Barrell, Ph. D., New Haven, Conn.; Asistant Professor of Geology, Yale University. December, 1902.

George H. Barton, B. S., Boston, Mass.; Curator, Boston Society of Natural History. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr, Pa.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

William S. Bayley, Ph. D., South Bethlehem, Pa. December, 1888.

*George F. Becker, Ph. D., Washington, D. C., U. S. Geological Survey.

Joshua W. Beede, Ph. D., Bloomington, Ind.; Instructor in Geology, Indiana University. December, 1902.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Acting Director of the Geological and Natural History Survey of Canada. May, 1889.

Charles P. Berkey, Ph. D., New York city; Columbia University. August, 1901.

Samuel Walker Beyer, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Arthur Bibbins, Ph. B., Baltimore, Md.; Instructor in Geology, Woman's College. December, 1903.

Albert S. Bickmore, Ph. D., American Museum of Natural History, New York; Professor in charge of Department of Public Instruction. December, 1889.

Irving P. Bishop, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

John Adams Bownocker, D. Sc., Columbus, Ohio.; Professor of Inorganic Geology, Ohio State University. December, 1904.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford, Jr., University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

Reginald W. Brock, M. A., Ottawa, Canada, Geologist, Geological and Natural History Survey of Canada; Professor of Geology, School of Mining, Kingston. December, 1904.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1899.

Ernest Robertson Buckley, Ph. D., Rolla, Mo.; State Geologist and Director of Bureau of Geology and Mines. June, 1902.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Franklin R. Carpenter, Ph. D., 1420 Josephine St., Denver, Colo.; Mining Engineer. May, 1889.

Ermine C. Case, Ph. D., Milwaukee, Wis.; Instructor in State Normal School. December, 1901.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Tacoma, Wash. August, 1891.

*William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Albany, N. Y.; State Paleontologist. December, 1897.

J. Morgan Clements, Ph. D., 11 William St., New York city. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

Arthur P. Coleman, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

George L. Collie, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

Arthur J. Collier, A. M., S. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. June, 1902.

*Theodore B. Comstock, Sc. D., Los Angeles, Cal.; Mining Engineer.

*Francis W. Cragin, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

Alja Robinson Crook, Ph. D., Evanston, Ill.; Professor of Mineralogy and Economic Geology in Northwestern University. December, 1898.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

GARRY E. CULVER, A. M. 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

EDGAR R. CUMINGS, Ph. D., Bloomington, Ind.; Assistant Professor of Geology, Indiana University. August, 1901.

*HENRY P. CUSHING, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

*NELSON H. DARTON, United States Geological Survey, Washington, D. C.

*WILLIAM M. DAVIS, S. B., M. E., Cambridge, Mass.; Sturgis-Hooper Professor of Geology in Harvard University.

DAVID T. DAY, Ph. D., U. S. Geol. Survey, Washington, D. C. August, 1891.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; No. 80 Rua Visconde do Rio Branco. December, 1890.

*JOSEPH S. DILLER, B. S., U. S. Geological Survey, Washington, D. C.

EDWARD V. D'INVILLIERS, E. M., 506 Walnut St., Philadelphia, Pa. Dec., 1888.

RICHARD E. DODGE, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

NOAH FIELDS DRAKE, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

CHARLES R. DRYER, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

*EDWIN T. DUMBLE, Austin, Texas; State Geologist.

*WILLIAM B. DWIGHT, Ph.B., Poughkeepsie, N.Y.; Professor of Natural History in Vassar College.

ARTHUR S. EAKLE, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

CHARLES R. EASTMAN, A. M., Ph. D., Cambridge, Mass.; In Charge of Vetebrate Paleontology, Museum of Comparative Zoology, Harvard University. December, 1895.

ARTHUR H. ELFTMAN, Ph. D., 706 Globe Building, Minneapolis, Minn. December, 1898.

*BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor in Amherst College.

*SAMUEL F. EMMONS, A. M., E. M., U. S. Geological Survey, Washington, D. C.

JOHN EYERMAN, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

HAROLD W. FAIRBANKS, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

*HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. FALES, Danville, Ky.; Professor in Centre College. December, 1888.

OLIVER C. FARRINGTON, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

NEVIN M. FENNEMAN, Ph. D., Madison, Wis.; Professor of Geology, University of Wisconsin. December, 1904.

AUGUST F. FOERSTE, Ph. D., 417 Grand Ave., Dayton, Ohio; Teacher of Sciences. December, 1899.

WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

*PERSIFOR FRAZER, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Horticultural Society of Pennsylvania.

*HOMER T. FULLER, Ph. D., Fredonia, N. Y.

Myron Leslie Fuller, S. B., U. S. Geological Survey, Washington, D. C. December, 1898.

Henry Stewart Gane, Ph. D., Santa Barbara, Cal. December, 1896.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

*Grove K. Gilbert, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

Adam Capen Gill, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

L. C. Glenn, Ph. D., Nashville, Tenn.; Professor of Geology in Vanderbilt University. June, 1900.

Charles H. Gordon, Ph. D., University Station, Seattle, Wash. August, 1893.

Charles Newton Gould, A. M., Norman, Okla.; Professor of Geology, University of Oklahoma. December, 1904.

Amadeus W. Grabau, S. M., S. D., Columbia University, New York city; Professor of Paleontology. December, 1898.

Ulysses Sherman Grant, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

Herbert E. Gregory, Ph. D., New Haven, Conn.; Assitant Professor of Physiography, Yale University. August, 1901.

George P. Grimsley, Ph. D., Morgantown, W. Va.; Assistant State Geologist, Geological Survey of West Virginia. August, 1895.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1902.

Frederic P. Gulliver, Ph. D., Norwichtown, Conn. August, 1895.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

*Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

Gilbert D. Harris, Ph. B., Ithaca, N. Y.; Assistant Professor of Paleontology and Stratigraphic Geology, Cornell University. December, 1903.

John Burchmore Harrison, M. A., F. I. C., F. G. S., Georgetown, British Guiana; Government Geologist. June, 1902.

John B. Hastings, M. E., 1480 High St., Denver, Colo. May, 1889.

*Erasmus Haworth, Ph. D., Lawrence, Kans.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

Richard R. Hice, B. S., Beaver, Pa. December, 1903.

*Eugene W. Hilgard, Ph. D., LL. D.; Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, Ph. D., Madison, Wis.; Professor of Mineralogy and Petrology, University of Wisconsin; Assistant Geologist, U. S. Geological Survey. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., N. Y. Botanical Garden, Bronx Park, New York; Instructor in Geology, Columbia University. August, 1893.

*Joseph A. Holmes, 6017 Cabanne Ave., Saint Louis, Mo.; State Geologist of North Carolina; In charge of investigation of fuels and structural materials, U. S. Geological Survey.

Thomas C. Hopkins, Ph. D., Syracuse, N. Y.; Professor of Geology, Syracuse University. December, 1894.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Associate Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

Ernest Howe, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. Wendell Jackson, Ph. B., 432 Saint Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Assistant Professor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Mark S. W. Jefferson, A. M., Ypsilanti, Mich.; Professor of Geography, Michigan State Normal School. December, 1904.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, Ph. D., Socorro, N. Mex.; President State School of Mines. August, 1890.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

Edward Henry Kraus, Ph. D., Ann Arbor, Mich.; Assistant Professor of Mineralogy, University of Michigan. June, 1902.

Henry B. Kummel, Ph. D., Trenton, N. J.; State Geologist. December, 1895.

*George F. Kunz, A. M. (Hon.), Ph. D. (Hon.), care of Tiffany & Co., 15 Union Square, New York city.

George Edgar Ladd, Ph. D., Rolla, Mo.; Director School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Alfred C. Lane, Ph. D., Lansing, Mich.; State Geologist of Michigan. December, 1889.

Daniel W. Langton, Ph. D., Fuller Building, New York city; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Professor of Geology and Mineralogy in the University of California. May, 1889.

Willis Thomas Lee, M. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

Charles K. Leith, Ph. D., Madison, Wis.; Professor of Geology, University of Wisconsin; Assistant Geologist, U. S. Geological Survey. December, 1902.

Arthur G. Leonard, Ph. D., Grand Forks, N. Dak.; Professor of Geology and State Geologist, State University of North Dakota. December, 1901.

Frank Leverett, B. S., Ann Arbor, Mich.; Geologist, U. S. Geological Survey. August, 1890.

William Libbey, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

Waldemar Lindgren, M. E., U. S. Geological Survey, Washington, D. C. August, 1890.

George Davis Louderback, Ph. D., Reno, Nev.; Professor of Geology, University of Nevada. June, 1902.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Thomas H. Macbride, A. M., Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Hiram Deyer McCaskey, B. S., Manila, P. I.; Chief of Mining Bureau of Manila. December, 1904.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August 1891.

***W J McGee**, LL. D., Director Public Museum, Saint Louis, Mo.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Curtis F. Marbut, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

Vernon F. Marsters, A. M., Bloomington, Ind.; Professor of Geology in Indiana State University. August, 1892.

George Curtis Martin, Ph. D., Washington, D. C.; U. S. Geological Survey. June, 1902.

Edward B. Mathews, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

William D. Matthew, Ph. D., New York City; Associate Curator in Vertebrate Paleontology, American Museum of Natural History. December, 1903.

P. H. Mell, M. E., Ph. D., Clemson College, S. C.; President of Clemson College. December, 1888.

Warren C. Mendenhall, B. S., 1108 Braly Building, Los Angeles, Cal.; Geologist U. S. Geological Survey. June, 1902.

John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

***Frederick J. H. Merrill**, Ph. D., 225 West End Ave., New York city; Consulting Geologist.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

Arthur M. Miller, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

Benjamin L. Miller, Ph. D., Bryn Mawr, Pa.; Associate in Geology, Bryn Mawr College. December, 1904.

Willet G. Miller, M. A., Toronto, Canada; Provincial Geologist of Ontario. December, 1902.

Henry Montgomery, Ph. D., Toronto, Canada; Professor of Geology and Biology, Trinity University. December, 1904.

*Frank L. Nason, A. B., West Haven, Conn.

John F. Newsom, A. M., Stanford University, Cal.; Associate Professor of Metallurgy and Mining. December, 1899.

William H. Niles, Ph. B., M. A., Boston, Mass.; Professor, Emeritus, of Geology, Massachusetts Institute of Technology; Professor of Geology, Wellesley College. August, 1891.

William H. Norton, M. A., Mount Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Lexington, Ky.; Professor of Mining, State College of Kentucky. August, 1894.

Cleophas C. O'Harra, Ph. D., Rapid City, S. Dak.; Professor of Mineralogy and Geology, South Dakota School of Mines. December, 1904.

Ezequiel Ordonez, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

*Amos O. Osborn, Waterville, Oneida county, N. Y.

Henry F. Osborn, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1894.

Charles Palache, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.

*Horace B. Patton, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

Frederick B. Peck, Ph. D., Easton, Pa.; Professor of Geology and Mineralogy, Lafayette College. August, 1901.

Samuel L. Penfield, Ph. B., M. A., New Haven, Conn.; Professor of Mineralogy, Sheffield Scientific School of Yale University. December, 1899.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

George H. Perkins, Ph. D., Burlington, Vt.; State Geologist. Professor of Geology, University of Vermont. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

Louis V. Pirsson, Ph. D., New Haven, Conn.; Professor of Physical Geology, Sheffield Scientific School of Yale University. August, 1894.

*Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

John Bonsall Porter, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

Joseph Hyde Pratt, Ph. D., Chapel Hill, N. C.; Mineralogist, North Carolina Geological Survey. December, 1898.

*Charles S. Prosser, M. S., Columbus, Ohio; Professor of Geology in Ohio State University.

*Raphael Pumpelly, U. S. Geological Survey, Dublin, N. H.

Albert Homer Perdue, B. A., Fayetteville, Ark.; Professor of Geology, University of Arkansas. December, 1904.

Frederick Leslie Ransome, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Charles H. Richardson, Ph. D., 884 Elm St., Manchester, N. H. December, 1899.

Heinrich Ries, Ph. D., Cornell University, Ithaca, N. Y.; Assistant Professor in Economic Geology. December, 1893.

*Israel C. Russell, LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Dallas, Texas.

Orestes H. St. John, Raton, N. Mex. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

Frank C. Schrader, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

Charles Schuchert, New Haven, Conn.; Curator, Geological Department, Yale University. August, 1895.

William B. Scott, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Arthur Edmund Seaman, B. S., Houghton, Mich.; Professor of Mineralogy and Geology, Michigan College of Mines. December, 1904.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1899.

*Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

George Burbank Shattuck, Ph. D., Baltimore, Md.; Associate Professor in Physiographic Geology, Johns Hopkins University. August, 1899.

Solon Shedd, A. B., Pullman, Wash.; Professor of Geology and Mineralogy, Washington Agricultural College. December, 1904.

Edward M. Shepard, A. M., Springfield, Mo.; Professor of Geology, Drury College. August, 1901.

Will H. Sherzer, M. S., Ysilanti, Mich.; Professor in State Normal School. December, 1890.

Bohumil Shimek, C. E., M. S., Iowa City, Iowa; Professor of Physiological Botany, University of Iowa. December, 1904.

*Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

*Eugene A. Smith, Ph. D., University, Tuscaloosa county, Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

Frank Clemes Smith, B. S., Harrisburg, Arizona; Mining Engineer. December, 1898.

George Otis Smith, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

William S. T. Smith, Ph. D., Box 30, Los Gatos, Cal. June, 1902.

*John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Professor of Mining and Metallurgy in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

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Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

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William J. Sutton, B. S., E. M., Victoria, B. C.; Geologist to E. and N. Railway Co. August, 1901.

Joseph A. Taff, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

James E. Talmage, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

Ralph S. Tarr, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

William G. Tight, M. S., Albuquerque, N. Mex.; President and Professor of Geology, University of New Mexico. August, 1897.

*James E. Todd, A. M., Vermilion, S. Dak.; Assistant Geologist, U. S. Geological Survey

*Henry W. Turner, B. S., 508 California St., San Francisco, Cal.

Joseph B. Tyrrell, M. A., B. Sc., Dawson, Y. T., Canada. May, 1889.

Johan A. Udden, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

Edward O. Ulrich, D. Sc., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*Warren Upham, A. M., Librarian Minnesota Historical Society, Saint Paul, Minn.

*Charles R. Van Hise, M. S., Ph. D., Madison, Wis.; President University of Wisconsin; Geologist, U. S. Geological Survey.

Frank Robertson Van Horn, Ph. D., Cleveland, Ohio; Professor of Geology and Mineralogy, Case School of Applied Science. December, 1898.

Gilbert vanIngen, Princeton, N. J.; Curator of Invertebrate Paleontology and Assistant in Geology, Princeton University. December, 1904.

Thomas Wayland Vaughn, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

*Anthony W. Vodges, San Diego, Cal.; Captain Fifth Artillery, U. S. Army.

*Marshman E. Wadsworth, Ph. D., State College, Pa.; Professor of Mining and Geology, Pennsylvania State College.

*Charles D. Walcott, LL. D., Washington, D. C.; Director U. S. Geological Survey.

Thomas L. Walker, Ph. D., Toronto, Canada; Professor of Mineralogy and Petrograhpy, University of Toronto. December, 1903.

Charles H. Warren, Ph. D., Boston, Mass.; Instructor in Geology, Massachusetts Institute of Technology. December, 1901.

Henry Stephens Washington, Ph. D., Locust, Monmouth Co., N. J.; August, 1896.

Thomas L. Watson, Ph. D., Blacksburg, Va.; Professor of Geology in Virginia Polytechnic Institute. June, 1900.

WALTER H. WEED, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

FRED. BOUGHTON WEEKS, Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

SAMUEL WEIDMAN, Ph. D., Madison, Wis.; Geologist, Wisconsin Geological and Natural History Survey. December, 1903.

STUART WELLER, B. S., Chicago, Ill.; Instructor in University of Chicago. June, 1900.

LEWIS G. WESTGATE, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

THOMAS C. WESTON, 591 Saint John St., Quebec, Canada. August, 1893.

DAVID WHITE, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

*ISRAEL C. WHITE, Ph. B., Morgantown, W. Va.

*ROBERT P. WHITFIELD, Ph. D., American Museum of Natural History, 78th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

*EDWARD H. WILLIAMS, JR., A. C., E. M., Andover, Mass.

*HENRY S. WILLIAMS, Ph. D., Ithaca, N. Y.; Professor of Geology and Head of Geological Department, Cornell University.

BAILEY WILLIS, U. S. Geological Survey, Washington, D. C. December, 1889.

SAMUEL W. WILLISTON, Ph. D., M. D., Chicago, Ill.; Professor of Paleontology, University of Chicago. December, 1889.

ARTHUR B. WILLMOTT, M. A., Sault Ste. Marie, Ontario, Canada. December, 1899.

ALFRED W. G. WILSON, Ph. D., Montreal, Ont., Canada; Demonstrator in Geology, McGill University. June, 1902.

ALEXANDER N. WINCHELL, Doct. U. Paris, Butte, Mont.; Professor of Geology and Mineralogy, Montana State School of Mines. August, 1901.

*HORACE VAUGHN WINCHELL, Butte, Montana; Geologist of the Anaconda Copper Mining Company.

*NEWTON H. WINCHELL, A. M., Minneapolis, Minn.; editor *American Geologist.*

*ARTHUR WINSLOW, B. S., 84 State St., Boston, Mass.

JOHN E. WOLFF, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

ROBERT S. WOODWARD, C. E., Columbia University, New York city; Professor of Mechanics and Mathematical Physics, Columbia University. May, 1889

JAY B. WOODWORTH, B. S., 24 Langdon St., Cambridge, Mass.; Assistant Professor of Geology, Harvard University. December, 1895.

FREDERIC E. WRIGHT, Ph. D., U. S. Geological Survey, Washington, D. C. December, 1903.

*G. FREDERICK WRIGHT, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary

WILLIAM S. YEATES, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894

FELLOWS DECEASED.

*Indicates Original Fellow (see article III of Constitution)

*CHARLES A. ASHBURNER, M. S., C. E. Died December 24, 1889.

CHARLES E. BEECHER, Ph. D. Died February 14, 1904.

Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
*Edward W. Claypole, D. Sc. Died August 17, 1901.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio Del Castillo. Died October 28, 1895.
*James D. Dana, LL. D. Died April 14, 1895.
George M. Dawson, D. Sc. Died March 2, 1901.
Sir J. William Dawson, LL. D. Died November 19, 1899.
*George H. Eldridge, A. B. Died June 29, 1905.
*Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1890.
*James Hall, LL. D. Died August 7, 1898.
John B. Hatcher, Ph. B. Died July 3, 1904.
*Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Alpheus Hyatt, B. S. Died January 15, 1902.
*Joseph F. James, M. S. Died March 29, 1897.
Wilbur C. Knight, B. S., A. M. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
*Joseph Le Conte, M. D., LL. D. Died July 6, 1901.
*J. Peter Lesley, LL. D. Died June 2, 1903.
Henry McCalley, A. M., C. E. Died November 20, 1904.
Oliver Margy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
James E. Mills, B. S. Died July 25, 1901.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*Peter Neff, M. A. Died May 11, 1903.
*John S. Newberry, M. D., LL.D. Died December 7, 1892.
*Edward Orton, Ph. D., LL. D. Died October 16, 1899.
*Richard Owen, LL. D. Died March 24, 1890.
*Franklin Platt. Died July 24, 1900.
*William H. Pettee, A. M. Died May 26, 1904.
*John Wesley Powell, LL. D. Died September 23, 1902.
*Charles Schaeffer, M. D. Died November 23, 1903.
Charles Wachsmuth. Died February 7, 1896.
Theodore G. White, Ph. D. Died July 7, 1901.
*George H. Williams, Ph. D. Died July 12, 1894.
*J. Francis Williams, Ph. D. Died November 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.
Albert A. Wright, Ph. D. Died April 2, 1905.

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